10:01:51 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 04/16/96

Active

Project #: E-20-W89 Cost share #: E-20-397 Rev #: 2
Center # : 10/24-6-R7945-3A0 Center shr #: 10/22-1-F7945-3A0 OCA file #:
Work type : RES
Contract#: U50/ATU499828-03 Mod #: ADM. REVISION Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 93.161
Main project #: PE #:

Project unit: CIVIL ENGR Unit code: 02.010.116
Project director(s):
ARAL M M CIVIL ENGR (404)894-2243

Sponsor/division names: DHHS/PHS/NIOSH/CDC / CENTER FOR DISEASE CONTROL
Sponsor/division codes: 108 / 002

Award period: 950930 to 960929 (performance) 961229 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	286,216.00
Funded	0.00	286,216.00
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Does subcontracting plan apply ?: N

Title: RESEARCH PROGRAM ON EXPOSURE-DOSE RECONSTRUCTION

PROJECT ADMINISTRATION DATA

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ATLANTA, GEORGIA 30305

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : supplemental sheet
Equipment title vests with: Sponsor X GIT
PROVIDE A COPY OF TITLE TO SPONSOR (ATSDR).
Administrative comments -
ISSUED TO REVISE BUDGET CATEGORIES. TITLE REMAINS WITH SPONSOR. CAPITAL OUTLAY WILL BE DECREASED, EQUIPMENT INCREASED.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

U

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 01/02/97

Project No. E-20-W89

Center No. 10/24-6-R7945-3A0

Project Director ARAL M M

School/Lab CIVIL ENGR

Sponsor DHHS/PHS/NIOSH/CDC/CENTER FOR DISEASE CONTROL

Contract/Grant No. U50/ATU499828-03

Contract Entity GTRC

Prime Contract No.

Title RESEARCH PROGRAM ON EXPOSURE-DOSE RECONSTRUCTION

Effective Completion Date 960929 (Performance) 961229 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

E-20-W89
N/A (new)

Annual Progress Report for Project Period 2

RESEARCH PROGRAM FOR EXPOSURE-DOSE RECONSTRUCTION

Submitted to:

Agency for Toxic Substances and Disease Registry (ATSDR)

Project Officer: Allan S. Susten, Ph.D. (DHAC, MS E-32)
Technical Project Officer: Morris L. Maslia, P.E. (DHAC, MS E-32)

Centers for Disease Control and Prevention and ATSDR
Award Reference No. U61/ATU499828-02

Submitted by:

Mustafa M. Aral, Ph.D.

Principal Investigator
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

February 10, 1996

TABLE OF CONTENTS

1. REVIEW OF RESEARCH ACTIVITIES FOR PROJECT YEAR 2

The cooperative agreement on Exposure-Dose Reconstruction Project (EDRP) was awarded to Dr. M. M. Aral, School of Civil and Environmental Engineering, Georgia Institute of Technology, towards the end of September 1993. Since then our efforts focused on several tasks of the research program in order to start the project in a most efficient and cost effective manner. We have successfully completed the first project period during the 1993-1994 academic year and the second project period during the academic year 1994 - 1995. The progress made during the first year of the research program was submitted to ATSDR, USDHHS, in an Annual Progress Report on January, 1995. We are now in the third project period (1995-1996) of the research program. A description of administrative efforts, research activities and the progress made in each activity during the second year of the research program are described in this second Annual Progress Report.

- **Purchase of the computational equipment:**

  The second phase of the purchase of the computer equipment necessary for the project has been completed. We anticipate that we will be adding to this equipment throughout the duration of the project as future needs arise. The equipment purchased for the Exposure Dose Reconstruction Research program is compatible with the present standards and other computational equipment used by ATSDR. With this equipment, direct communication between ATSDR and Ga. Tech has been established through ethernet communication platform. It is also anticipated that the compatibility established between the equipment at both sites will enhance the technology transfer phase of the research program which is anticipated to occur during later stages of the research program.

- **Development of the analytical framework for the prediction of contaminant migration scenarios in multiple exposure pathways:**

  It is anticipated that the contaminant migration analysis (the forward pathway calculation environment) will include several analytical tools to evaluate the contaminant concentration levels in multiple and interactive pathways. These pathways, at a minimum, will include the following:

  (i) air pathway;
  (ii) ground-water pathway;
  (iii) surface water pathway; and,
  (iv) soil pathway.

  According to the proposed schedule of the research program, the analytic tools for these pathways will be developed throughout the duration of the project. During the first project year, it was extremely important to conceptualize the overall system and develop a unified analytical structure and a user friendly framework for this computational environment. As parts of the overall system are developed, and several analytical tools are put together, this unified structure will provide the framework necessary for a user friendly computational environment. This approach will also minimize the revisions that will be necessary during the later stages of the research program. Major portion of this task was completed during the first project year. Although this software development effort may not be in its final form, the initial

computational tool developed for the ground-water pathway and submitted to ATSDR during the first project period, indicate our line of taught for the general computational environment we are developing in this effort. During the second project period, the first years initial effort was modified significantly resulting in a major upgrade of the overall product. The new version of the software was submitted to ATSDR for beta testing during April and also on December 1995 (ACTS version 1.2). This version of the software is now more user friendly and more computationally efficient. In this tool several analytic solutions for the ground-water pathway and also the air pathway was developed along with a graphical and text output format interphase which may be used to interpret the results. This version now also includes the Monte Carlo simulations for the air pathway analysis as described in more detail below. This is an essential component of for this pathway since the inherent uncertainties of the computations in the air pathway is much more pronounced. This software will be updated throughout the project period to include analytical tools for other pathways mentioned above as well as other revisions that may be recommended by ATSDR. In it's present form the computational tool submitted to ATSDR can be used to evaluate concentration distributions in site specific cases for the ground-water pathway and air pathway. This software can be installed in ATSDR's network system for immediate access by all health professionals. At the present this computational tool is tested and used successfully in several site specific applications by ATSDR professionals.

- Monte Carlo simulations in analytic contaminant migration analysis:

As was proposed in our first year progress report, an important component of the second project period effort was the incorporation of evaluation of the uncertainties involved in analytic contaminant migration simulations. Evaluation of the effect of these uncertainties on the numerical results generated can be accomplished using Monte Carlo methods.

Implementation of analytical tools in all pathways requires a number of input parameters including source-specific, media-specific, and chemical-specific variables. Typically, the values of these parameters are not known exactly due to measurement errors and/or inherent spatial and temporal variability. Therefore, it is often more appropriate to express these parameter values in terms of a probability distribution rather than a single deterministic value and use an uncertainty propagation model to assess the effect of the variability on the output of the models. Most suitable method that can be employed for this purpose is the Monte Carlo method. Based on the principles of this approach, the following procedure is incorporated to the software developed for ATSDR.

Whatever the source of the parameter uncertainty, the uncertainty can be quantified using a cumulative probability distribution. Thus, for each parameter to be analyzed as an uncertain variable, the user may select and assign a probability distribution (normal, log normal, uniform, exponential, triangular) for the variable and specify the parameters that describe the distribution. In Monte Carlo simulations, data sets randomly generated from these distributions form the basis of the data sets that will be used in deterministic models which in turn will generate a population of model outputs. This series of outputs can than be analyzed to yield a cumulative probability distribution of expected model results. This distribution quantitatively describes the uncertainty in the model output and can be used in decision making.

During the second project year, considerable effort was devoted to introduce Monte Carlo simulation tools into the overall computational framework developed in the first project year. With this component added to the system, users will have the choice to select between direct calculations (deterministic mode computations) and Monte Carlo simulations in pathway analysis exercises based on the confidence they have on the parameters they are using in their applications. With the addition of Monte Carlo methods, the flexibility and reliability of the computational system is improved and the applicability of the overall system is enhanced. At the present this computational system is included into the air pathway calculations. During later stages of the project we intend to expand this capability to other pathway calculations also.

- **An application study for contaminant transport analysis in pipe network systems and GIS based evaluation of exposure assessment for a site specific case:**

ATSDR and the Connecticut Department of Health Services (CDHS) are collaborating in a study of cancer incidence in the Town of Southington, Hartford County, Connecticut. As part of the study, ATSDR is determining population exposure to contaminated groundwater that was distributed in the town's water distribution system. To address the complex engineering issues associated with exposure assessment, ATSDR relied on the resources of the Exposure-Dose Reconstruction Cooperative Agreement Project. The main problem in addressing this issue was the time limitations imposed on ATSDR to find a solution to the problem. A solution to the problem was requested by CDHS within a period of 4 to 6 months. Based on this request ATSDR Exposure-Dose Reconstruction project officer contacted Ga Tech research program during September 1994 an requested us to devote our efforts to solve the problem and provide them with the analysis results within a period of 4 to 6 months. In order to address this urgent problem Ga Tech principal investigator decided to allocate all resources of the project to finding a solution to this problem and providing ATSDR with reliable estimates of exposure using GIS integrated pipe network analysis. The project was completed in time and the results were submitted to ATSDR in a final report titled "A Public Health Analysis of Exposure to Contaminated Municipal Water Supplies at Southington, Hartford County, Connecticut."

This research effort, was not included to the initial research program proposed by the principal investigator, and was undertaken as an additional effort at the request of ATSDR project officers. Since the problem posed to ATSDR by the CDHS is an extremely important health assessment problem with nationwide applications and the engineering analysis provided by Ga. Tech is an extremely useful and practical but preliminary solution to the problem at hand, the Ga Tech principal investigator recommends that ATSDR may like to pursue this research in the future. This unplanned research effort requested by ATSDR delayed the ongoing efforts at Ga Tech by two quarters during the second year of the research program.

- **Development of user friendly GIS interface programs:**

It is our understanding that ATSDR's needs for computational tools in the area of health assessment is multilevel. The range of complexity of these tools may vary between screening tools, similar to the analytical computational environment described above, to the sophisticated GIS integrated multimedia modeling tools which may be used to analyze more complex cases. Given the number of sites that needs to be analyzed by ATSDR periodically and given the variability in complexity of the contaminant migration pathways in these sites, there would be a need for sophisticated approaches as well as the screening tools. Thus, in addition to the analytical tool development phase of the project, we are also in the process of developing user friendly GIS interface programs to simplify the analysis steps necessary in these complex cases. Our initial efforts in category was concentrated towards the development of a shell structure for the GISPlus software which is presently used by ATSDR. This shell program will simplify the manipulation of data structures within a GIS integrated computation and the interaction of the complex simulation tools with the GIS system. The preliminary shell structure submitted to ATSDR during the first period of the project may describe our line of thought in this effort. Although this shell program will be updated throughout the project period, in its present form it is being tested and used to evaluate site specific conditions for the ground-water pathway at ATSDR and Ga. Tech. In this effort, in addition to the general shell structure submitted to ATSDR, certain coordinate transformation routines and data base generation routines, compatible with the existing ground-water flow and contaminant transport models, has been developed and submitted to ATSDR for beta testing. These codes were tested and used successfully in site specific applications by ATSDR professionals. This aspect of the research program is still under development and revisions to the code will be supplied to ATSDR for their beta testing.

- **Adaptation of existing ground-water flow models to GISPlus software:**

  The PC-based GIS system in use at ATSDR is the GISPlus system. The implementation of existing ground-water pathway analysis tools required substantial revision of these codes to make them compatible with the GISPlus system. Although this is an ongoing task, our initial efforts provided ATSDR with these tools which are now in use in predicting ground-water flow patterns in several sites of interest to ATSDR. We are in the process of adding contaminant transport models to this system in the area of subsurface analysis. These codes were tested and used in site specific applications by ATSDR professionals during the second period of the research program and the results are shared with several federal and state agencies involved in the program.

  ATSDR also utilizes ARC-INFO software in their site investigation studies. We are also working to move the ground-water pathway analysis tools to PC-ARCINFO platform as an additional extension of the existing workload.

2. PRODUCTS SUBMITTED TO ATSDR, USDHHS

During the second year of the cooperative agreement the following computational software were submitted to ATSDR for their evaluation and beta testing. Some of this software are still in the development stage and should not be considered to be a final product. All of these products are presently used by ATSDR health assessors in evaluating health consequences of contaminants released to subsurface pathways.

(i) Analytical Contaminant Transport analysis System (ACTS Version 2.0)
(ii) GIS Interphase SYStem (GIS-SYS Version 1.20)

3. RESEARCH ACTIVITIES FOR PROJECT YEAR 3

As the second year effort, the progress made in all of the activities summarized above are substantial. This progress was in addition to an unplanned GIS based Pipe Network Analysis research activity requested by ATSDR. Ga Tech project director welcomes such requests since in our cooperative agreement the basic goal is to satisfy the technical needs of ATSDR as they arise and provide ATSDR with expertise utilizing resources of Ga. Tech. This effort was an excellent example of this cooperation.

Our ongoing efforts will be directed towards the completion of the tasks and improving the tools we are developing for ATSDR during the next two years of the project period. In this effort, additional pathways described above will be incorporated into the computational environment. These tools will be periodically submitted to ATSDR for their evaluation and beta testing.

The primary pathway that will be analyzed during the third project period is selected to be the surface water pathway. Analytical tools that will be developed to evaluate exposure in this pathway will include, near field far field surface water diffusion dispersion models. Monte Carlo simulations will also be incorporated into this analysis. Details of this computational processes were described in the original proposal submitted to ATSDR which will not be repeated here.

4. TECHNICAL PUBLICATIONS

Based on the progress made during the second year of the research program, several technical publications and reports were published or submitted for publication. These research reports or technical papers are the outcome of the research effort of the second project year. The following technical publications were accepted for publication in refereed journals or were accepted for inclusion in the proceedings of the conferences listed below.

1. M. L. Maslia, M. M. Aral, R. C. Williams, R., A. Susten and J. L. Heitgerd, "Exposure Assessment of Populations Using Environmental Modeling, Demographic Analysis, and GIS," Water Resources Bulletin, Vol. 30, No. 6, pp. 1025-1041, 1994.

2. Maslia, M. L. and Aral, M. M., "Application of Geographic Information Systems and Numerical Models to Exposure Assessment", Sixth Joint Conference of the International Society for Environmental Epidemiology and International Society for Exposure Analysis, The University of North Carolina at Chapel Hill, September 18-21, 1994.

3. Aral, M. M. and M. L. Maslia, "A Public Health Analysis of Exposure to Contaminated Municipal Water Supplies at Southington, Hartford County, Connecticut," School of Civil Engineering, Georgia Institute of Technology Final Report submitted to ATSDR as a part of Exposure-Dose Reconstruction Research Program, p 42, December 20, 1994.

4. Aral, M. M. and M. L. Maslia, "A Public Health Analysis of Exposure to Contaminated Municipal Water Supplies at Southington, Hartford County, Connecticut," *Archives of Environmental Health*, (submitted for publication)1994.

BIOGRAPHICAL SKETCH

Dr. Mustafa M. Aral

Personal Data Summary

Born	: February 26, 1945, Ankara, Turkey
Citizenship	: U.S.A.
Home Address	: 2974 Cravey Dr. NE., Atlanta, GA. 30345

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Professional Registration

Professional Engineer : GA : 15254
Professional Ground Water Hydrologist, National Registration : No.: 649

Educational Background

School of Civil Engineering, Georgia Institute of Technology, Ph.D. in Water Resources Engineering with minor in Numerical Analysis and Applied Mathematics, September 1971.

School of Civil Engineering, Georgia Institute of Technology, M.S. in Civil Engineering with major in Environmental and Water Resources Engineering, June 1969.

Department of Civil Engineering, Middle East Technical University (Ankara, Turkey), B.S. in Civil Engineering, June 1967.

Professional Experience

1983-present	Professor	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1983-1995	Associate Professor	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1978-1983	Visiting Professor	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1974-1983	Adjunct Professor	At Marine Sciences Department, Civil Engineering Department, Engineering Science Department, Middle East Technical University.

Professional Experience (cont.)

1977-1983	Associate Professor	Mathematics Department, Middle East Technical University.
1975-1978	Assistant Chairman	Mathematics Department, Middle East Technical University.
1971-1977	Assistant Professor	Mathematics Department, Middle East Technical University.

Publications

42. Aral, M. M., Ground Water Modeling in Multilayer Aquifers - Steady Flow, *Lewis Publishers Inc.*, February, 1990 (Book).

43. Aral, M. M., Ground Water Modeling in Multilayer Aquifers - Unsteady Flow, *Lewis Publishers Inc.*, March, 1990 (Book).

44. Tang, Y., and Aral, M. M., Contaminant Transport in Layered Porous Media: A. General Solution, *Water Resources Research*, Vol. 28, No. 5, pp. 1389-1397, 1992.

45. Tang, Y., and Aral, M. M., Contaminant Transport in Layered Porous Media: B. Applications, *Water Resources Research*, Vol. 28, No. 5, pp. 1399-1406, 1992.

46. Ratzlaff, S., Aral, M. M., and Alkhayyal, F., Optimal Capture Zone Design Using Segmental Velocity Direction Constraints, *Groundwater Journal*, Vol. 30, No. 4, pp. 607-612, 1992.

47. Aral, M. M., and Tang, Y. Flow Against Dispersion in Two Dimensional Aquifers, *Journal of Hydrology*, Vol. 140, pp. 261-277, 1992.

48. Maslia, M., Aral, M. M., and Houlihan, M., "Evaluation of Ground-Water Flow Regime at a Landfill with Liner System," *Journal of Environmental Science and Health*, Vol. A27, No. 7, pp. 1793-1816, 1992.

49. Maslia, M., Aral, M. M., and Gill, H. E., "The Importance of Hydrogeologic Controls on Remedial Action Alternatives," *Geophysical Society of America*, Southeastern Section Meeting, Contaminant Hydrogeology Session, Vol. 24, No. 2, pp. 53, 1992.

50. Maslia, M., Aral, M. M., Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Determine Health Implications of Human Exposure Resulting from Remediation Activities at Hazardous Waste Sites," Report for: *Division of Health Assessment and Consultation, DHHS-ATSDR*, 20p, November 5, 1992.

51. Aral, M. M., Maslia, M. and Williams, R., "Integration of GIS and Environmental Transport Models for Exposure Assessment of Populations," Water Resources Bulletin, (submitted for publication), 1993.

52. Maslia, M., Aral, M. M., Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of

Computational Models to Determine Human Exposure Resulting from Remediation Activities at Hazardous Waste Sites," Proceedings of the Water Environment Federation Specialty Conference *How Clean is Clean*, 85p, January 10-13, 1993.

53. Maslia, M., Aral, M. M., Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Reconstruct and Predict Trichloroethylene Exposure," Proceedings of the International Congress on the Health Effects of Hazardous Waste, 22p, 1993.

54. Aral, M. M., Maslia, M., and Williams, R., "Ground-Water Remediation Using Smart Pump-and Treat," *Ground Water Journal*, Discussion, Vol. 31, No. 4, pp. 680-681, 1993.

55. Aral, M. M., C. Shea and Al-Khayyal, F., "Optimization Methods in Ground Water Management," Review Chapter in Volume 9, "Applications of Management Science: Network Optimization Applications," JAI Press Inc., 1993 (in publication).

56. Maslia, M. L. and Aral, M. M., "Health Implications Associated with Hazardous Waste Site Clean-Up Goals: A Case Study of Trichloroethylene (TCE) Contamination", Proceedings of the Annual Meeting of the Geological Society of America, Boston, 1993.

57. Maslia, M. L. and Aral, M. M., "Conducting Exposure Assessment of Populations by Integrating Environmental Transport Models, Demographic Analysis, and Geographic Information Systems", Proceedings of the International Symposium on Assessing and Managing Health Risks from Drinking Water Contamination: Approaches and Applications, Rome, Italy, September 1994.

Expertise Areas

Research, teaching and engineering experience in the following specific areas :

- Fluid mechanics, Hydraulics Engineering
- Environmental simulations and fate
- Analytical and numerical studies in surface water, ground-water and air pollution
- Evaluation of ground water and surface water monitoring data
- Ground water flow and contaminant transport modeling in aquifers
- Ground water resources evaluation and management
- Disposal and ground water quality effects of hazardous substances, aquifer remediation
- Saturated and unsaturated ground water flow analysis
- Miscible and immiscible ground water flow analysis
- GIS applications in environmental systems

PAPERS IN PUBLICATION

ESTIMATING EXPOSURE TO VOCS FROM MUNICIPAL WATER SUPPLY SYSTEMS: USE OF A BETTER COMPUTATIONAL MODEL

M.M. Aral[a], M.L. Maslia, G. Ulirsch, and J.J. Reyes[b]

ABSTRACT

The Southington, Connecticut, water supply system is characterized by a distribution network containing more than 1,700 pipeline segments of varying diameters and construction materials, more than 186 miles of pipe, 9 groundwater extraction wells capable of pumping more than 4,700 gallons per minute, and 3 municipal reservoirs.[c] Volatile organic compounds (VOCs) contaminated the underlying groundwater reservoir during the 1970s. This resulted in contamination of the water supply system and exposure of the town's residents to VOCs. A computational model was applied to the water supply system to characterize and quantify the distribution of VOCs in the pipelines and to estimate the demographic distribution of potential exposure to the town's residents. Based on results from modeling analyses, we conclude: (1) exposure to VOC contamination may vary significantly from one census block to another even when these census blocks are adjacent to each other within a specified radius; (2) maximum spatial spread of contamination in a water distribution system may not occur under peak demand conditions. Thus, maximum spatial distribution of the

[a]Associate Professor, School of Civil Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332.

[b]Respectively, Research Hydrologist and Technical Project Officer, Environmental Engineer, and Deputy Director, Division of Health Assessment and Consultation, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road, Mail Stop E-32, Atlanta, Georgia 30332.

[c]Refer to Appendix I for factors to be used for converting from the English units used in the text to SI units and the accompanying abbreviations.

exposed population also may not correspond to peak demand conditions; and (3) the use of the proposed computational model allows for a more refined and rigorous methodology to estimate census block level contamination for exposure assessment and epidemiologic investigations.

INTRODUCTION

Public health professionals continuously seek more refined methods to characterize populations exposed to environmental contamination. Such studies are conducted for a variety of purposes, including: (1) identifying populations at risk from environmental hazards, (2) conducting exposure assessments of sensitive populations, (3) identifying areas for the focus of public health education or community outreach, and (4) identifying target and control populations for health studies. For example, measured environmental concentrations of toxic substances, when coupled with simulation models and subjected to statistical analyses, can be used to determine risks to potentially exposed communities. Likewise, where insufficient environmental measurements exist for adequate (or proper) characterization, environmental fate and transport models may be used for such characterization. Geographic Information Systems (GIS), coupled with census information and spatial environmental analysis techniques, offer tools which allow assessment of the size and demographic characteristics of populations in concert with the evaluation of environmental and health data. We review one such tool that may be used to evaluate exposure of populations via water distribution systems.

The Solvents Recovery Services of New England (SRSNE) site, located in the town of

Southington, Connecticut (Figure 1), has been listed by the U.S. Environmental Protection Agency (EPA) as a National Priorities List (NPL) site. It was operated as a hazardous waste treatment and handling facility from 1955 to March 1991 which processed 3 to 5 Mgal of liquid and 100,000 lb of solid hazardous wastes annually. Groundwater contamination at SRSNE has been documented since 1965, when an SRSNE bedrock well was reported to be contaminated with VOCs. Hydrogeologic investigations and groundwater sampling data suggest that most of the contaminated groundwater in the uppermost aquifer has migrated towards the south and southeast. The Southington Water Company's (SWC) production wells 4 and 6 are located about 1,200 ft south of the SRSNE (Figure 1). Well 4 was installed in 1966 and well 6 in 1976. Well 5, installed in 1972, is located approximately 4 mi south of the SRSNE site; its contamination has not been directly linked to the site but, as reported, may be the result of landfill operations and disposal practices at the Old Southington Landfill.[1] Groundwater samples from wells 4, 5, and 6 were identified as contaminated with VOCs and possibly with heavy metals in 1976 and 1977. Water from all three wells was distributed through the town's water supply system, thereby potentially exposing a large population to contaminated water. A more complete description of the site and evaluation of its public health implications is presented in Agency for Toxic Substances and Disease Registry's (ATSDR) public health assessment of the SRSNE site.[1]

In this paper, we present the methods used to evaluate the VOC distribution through the town of Southington's water supply system and the methods used to link these results to exposure analysis. Unlike simplified, closed-form mathematical solutions that require a water distribution system of limited and specific geometric configurations,[2] our approach uses a computational algorithm that can be applied to any generalized water distribution network configuration that may consist of thousands of pipeline segments and numerous pump stations, reservoirs, and valves. In our analysis we also demonstrate the use of spatial analysis techniques (GIS) to link contaminant distribution in water supply systems with census block data bases to evaluate exposure to humans. The application reviewed in this paper demonstrates that the proposed computational model provides health scientists and public health professionals with a refined method that may enable them to quantify areas of past exposure and possible public health concern more rigorously. The proposed approach yielded results that generally contradict a commonly held assumption that all residents within a constant radius of a contaminated water supply well would be exposed to contaminated groundwater extracted from the well (i.e., the "1-mile radius" approximation), or that all residents throughout the entire water distribution system may have been exposed to contaminants that could have exceeded a health criterion (such as the maximum contaminant level for VOCs). Thus, the methodology described below is valuable for exposure assessment in epidemiologic investigations that attempt to define the public health implications of such problems.

STUDY APPROACH

Assessing the distribution of contaminants in a water distribution system and estimating the population exposed to contaminated water is a complex problem for which analysis requires a multidisciplinary approach. For a typical study, the following components may be involved: (1)

analysis of the pumping stress placed on groundwater resources by the extraction wells, (2) the fate and transport of contaminants in the subsurface and their movement in response to groundwater extraction, (3) the hydraulic characteristics of the water distribution system, (4) contaminant distribution within a water supply network, and (5) spatial analysis with respect to the location of census subdivisions as they relate to the contaminant distribution in the water supply network. In the study presented here our focus area are the items (3), (4) and (5) described above. Thus, we assume: (1) transient effects of turning on and off different pumping wells are negligible and the flow in the groundwater reservoir system, no matter which wells are pumping, reaches steady state rapidly; (2) the contamination measured in water samples from wells 4, 5, and 6 represents sources of contamination that do not vary over time, and measured concentrations represent maximum values as conservative estimates; and (3) the distribution of contaminants in the water distribution network is at steady state after 24 hours from initial contamination. The last assumption was based on sensitivity analyses conducted on the hydraulics of the water distribution system studied.

The implications of the assumptions described above are as follows: (1) for a selected scenario the water distribution system has a constant supply of water that will not vary over time; (2) the movement of the contaminant plume from the source of contamination to the extraction wells is ignored. These assumptions are made to simplify the presentation of the main topic of this paper. In other studies we demonstrate the use of subsurface fate-and-transport analysis more rigorously[4]; and (3) simulation of the water distribution system over a 24-hour period can be used to represent any 24-hour operational period as long as we know which extraction wells were operating.

Because of the massive quantity of data required for an analysis of this type, we chose to use a GIS to help manage, manipulate, analyze, and query the data. A GIS provides a computational platform in which layered, spatially distributed databases can be manipulated easily and whereby certain topological attributes, which may not be known *a priori*, can be queried to obtain the spatial relationship between environmental and infrastructure parameters and demographic distributions. For this study, we used the GisPlus software package, which runs on a standard IBM compatible personal computer environment.[3] A more detailed description of the use and application of GIS for exposure assessment studies related to groundwater contamination problems can be found in Maslia et al.[4] and Aral and Maslia.[5]

HYDRAULIC AND CHEMICAL FATE MODELING

Hydraulic and chemical fate modeling of water distribution systems can be conducted by solving mathematical equations that characterizes the pipe network distribution system. A simple example of such an application was presented in Webler and Brown.[2] However, there are disadvantages to the proposed approach: (1) the quantity of pipelines that can be modeled must be kept unrealistically small so that the algebra involved does not get too complicated, and (2) pipelines that can be modeled must be limited to unrealistically simple representations of actual pipe-network systems (e.g., the straight, "dead-end" pipe or circular geometries as presented in Webler and Brown[2]).

Because of the complex and nonuniform nature of the pipeline network system for the town of Southington (Figure 1), we chose to use a computational program that simulates hydraulic and water quality behavior within generalized water distribution systems. The computer program, EPANET, tracks the flow of water within each pipe segment, the pressure at each pipe junction or node, the height of water in each reservoir or storage tank, and the concentration of a substance (contaminant) throughout a distribution system during a multi-period simulation, irrespective of the geometry and configuration of the pipeline network. EPANET runs on an IBM/386 (or higher models) or compatible computers with 640K memory under the DOS and WINDOWS™ operating systems which is widely available configuration for desk top computers. Details of the program and the mathematical theory supporting the hydraulic and water quality modeling capabilities of the code may be found in Rossman[6] and Rossman and Clark.[7]

Configuration of the water distribution system (Figure 1) and data pertaining to the physical characteristics of pipes (length, diameter, resistance coefficient, hydraulic grade line, location of pipe junctions, elevation of pipe junctions, and water demand) were obtained from information supplied by the Connecticut Department of Health Services (CDHS) and the SWC. Pipe and hydrant locations were digitized into a GIS database from a water distribution system map supplied by the SWC. Data on pipe resistance coefficients (Hazen-Williams C), pipe junction and hydrant elevations, and water demand were not available for each individual pipe and pipe junction for the system shown in Figure 1, but rather for an equivalent network system, which was not useful for our analysis. Therefore, average values for the resistance coefficient, pipe junction elevation, and water demand of 99.2, 203.7 ft, and 5 gal/min, respectively, determined from the equivalent pipe network data, were used for the input data to the water distribution system shown in Figure 1. The variability of the first and last variables listed above is not very significant and the variability of the pipe junction elevations is a function of the topography of the region under study.

The SWC obtains its water supply by pumping nine municipal wells that extract groundwater at varying rates. The water extracted by these wells is then pumped into the distribution system. Thus, when wells 4, 5, and 6 became contaminated with VOCs, the contaminated groundwater was mixed with water pumped from other wells and distributed within the water distribution system. For the purposes of our analysis, we conducted four different simulations to represent as closely as possible (based on available data) the configuration of the water distribution system and operation of the pumping wells during the period of contamination. These simulations represent the following pumping configurations and contaminated wells (Table 1): (1) Scenario I, 1970 conditions, well 4 contaminated; (2) Scenario II, 1974 conditions, wells 4 and 5 contaminated; (3) Scenario III, 1979 conditions, wells 5 and 6 contaminated; and (4) Scenario IV, maximum pumping (peak demand) conditions, wells 4, 5, and 6 contaminated.

We used the data described above to run the computational model for each of the four scenarios. The output from the model was retrieved and placed into a database for use with the GIS. The database contains information on pipe hydrant locations and elevations, water demand, hydraulic grade, pressure, and chemical concentration at each junction and pipe. For each simulation scenario, the pipe hydrants that were simulated as being contaminated (chemical concentrations greater than 0 ppb) were selected by use of the querying, selection, and aggregation capabilities of the GIS.

Figures 2A through 2D show the distribution and location of pipe hydrants (black dots) that were simulated as being contaminated for Scenarios I, II, III, and IV, respectively. Using this output, the distribution of contaminant concentrations within the water supply system could be presented as contaminant concentration contours by applying any general purpose contouring program capable of using irregularly spaced data points. However, owing to space limitations, we will omit this analysis and proceed in the section below with relating the pipe hydrant data to census geographical area distributions.

SPATIAL ANALYSIS

Spatial analysis involves evaluations that examine data characterized by location, shape, and relationship among geographic features, usually stored as coordinates and topology, with the intent of extracting or creating new data that fulfill some required condition or conditions.[8] Applying this definition to the current study required the identification of census subdivisions that were served by contaminated municipal water from the SWC's water distribution system. That is, we needed to relate the location of contaminated pipe hydrants (Figure 2) to the location of specific census subdivisions in the town of Southington where the pipe junctions are located. Additionally, we determined the distribution and range of contaminants within the census subdivision areas served by the contaminated water distribution system. In this article, we present results solely for total VOCs, although our study contained analyses for such other contaminants such as 1,1,1 trichloroethane (TCA) and 1,1,2 trichloroethylene (TCE).[5]

The United States is subdivided into political (e.g., county) and census statistical (e.g., tract, block group, and block) geographic areas for which population data are tabulated. In 1990, for the first time, the entire United States was subdivided into census blocks. The geographic census block data are available in digital format on CD-ROM through the Bureau of the Census' TIGER/Line files.[9] Block level census data prior to 1990 (e.g., 1980 and 1970) may not be available in digital form for certain areas in the country. For these years, the census block data must be reconstructed using other sources, or may be developed using the earlier census tract boundaries to arrive at estimated population figures. Contamination considered in this study occurred during the 1970s, and census block data for this time period were not readily available. Therefore, we estimated these data by imposing census block boundaries from 1980 onto 1970 census tract boundaries and calculated population totals.

To begin our analysis, we used the querying and aggregating operations of our GIS and compiled all census block areas that contained pipe hydrants with simulated contaminant concentrations greater than 0 ppb. During these analyses, we aggregated contaminant levels for each census block by minimum, maximum, and mean values. The results of these analyses, which are contaminated census block areas, are shown in Figures 3A-3D for simulation scenarios I (1970 conditions), II (1974 conditions), III (1979 conditions), and IV (peak demand conditions), respectively. In Figure 3, the shaded areas indicate the range of maximum concentration of total VOCs in ppb for the census block areas served by the contaminated pipelines. Table 2 lists the number of census blocks estimated to have been served by contaminated water from the water distribution system and the total population for those census blocks.

To compare our results with results from an approach commonly used to estimate exposure within a 1-mile radius of a contaminated site or well (the "1-mile radius" approach), we used the GIS spatial analysis capability. By overlaying the area derived from a 1-mile radius around the contaminated wells, we computed estimates of the census blocks and population exposed to contaminated water for the four simulation scenarios. Table 2 lists the estimated population exposed to contaminated water derived from this method. Additionally, we compared the census blocks estimated to have been served by contaminated pipelines as previously described (Figure 3) with the 1-mile radii circles around the contaminated wells for each simulation scenario. These results are shown in Figures 4A through 4D.

DISCUSSION OF RESULTS

To estimate the population that may have been exposed to contaminated municipal water supplies in Southington, Connecticut, we conducted four simulations of the water distribution system. The simulations represented pumping conditions for 1970, 1974, 1979, and peak demand based on data supplied by the CDHS. Results of these simulations indicate that spatial distribution of contamination is sensitive to and may be a function of the location and number of wells that are pumping. For example, in scenario I, only four wells are pumping and only well 4 is contaminated (Table 1). This results in the smallest area of contamination of the four simulations (Figures 2A and 3A). However, maximum pumping demand, scenario IV, with all of the wells pumping and wells

4, 5, and 6 contaminated (Table 1), does not produce the largest area of exposure when compared with scenarios II and III (compare Figures 3B and 3C with Figure 3D). Analysis of the hydraulics of the water distribution system for each simulation scenario will lead to an explanation of this seeming discrepancy. In scenarios II and III, wells 7 and 8 are not in service (Table 1); these wells are located in the southeastern part of Southington (Figure 2). In order to supply the demand for water to that part of Southington, the water distribution system must deliver water from the more western and northern parts of the distribution system. Thus, contaminated water from wells 4, 5, or 6 is routed to the southeastern part of Southington, thereby delivering contaminated water to that area of the town. On the other hand, when all wells are pumping (scenario IV, peak demand conditions, Table 1), wells 7 and 8 are used to satisfy the water demand for the southeastern part of town. Because these wells are providing water that is not contaminated, and the demand in the southeastern part of town is completely satisfied, there is no need for the water distribution system to deliver contaminated water to the more western and northern parts of the town.

Results of simulation scenarios II and III indicate that the same census blocks are exposed for each scenario, although pumping and contamination conditions vary (Figures 3B and 3C). The distribution of exposed census blocks should be nearly the same because wells 4 and 6 are located within a few feet of each other. However, our analysis shows that there is a significant difference in the contaminant concentration values computed for each census block based on the two scenarios (compare Figures 3B and 3C). This result could have an important impact on the design of exposure assessment studies and subsequent public health evaluations because of the difference in contaminant levels to which the population was exposed.

Our analysis also demonstrate the inadequacy of the common approach used to estimate exposed populations by drawing a circle of a constant radius around the source of contamination (the "1-mile radius" approach). This approach is not a good estimator to identify census areas serviced by contaminated water in a distribution system such as the one in Southington. Our results indicate that census blocks served by contaminated water are generally to the east of contaminated wells (Figures 2 and 3). This is because of the hydraulic characteristics of the water distribution system, which can only be determined through the use of the computational program previously described. If we have used a radius of 1 mile centered at the contaminated wells, we would have concluded that the census blocks to the west of the wells are also contaminated. This approach, therefore, would identify a population incorrectly, assuming they had been serviced by and exposed to contaminated water when in fact they had not.

Finally, an observation that can be made from our analysis is that when applying the "1-mile radius" approach for estimating exposure, it is generally assumed that the concentration of the contaminated water within the 1-mile radius area is constant. Results obtained by using the computational model indicate that there is a noticeable spatial variation in levels of contamination within the exposed census block areas (Figure 3). Thus, assuming a constant concentration for exposure analysis purposes could yield inaccurate estimates of exposure that could have an impact on public health decisions.

CONCLUSIONS

The methodology and analysis presented in this paper have provided us with the ability to estimate; (1) the extent and location of the water supply system that distributed groundwater contaminated with total VOCs, and (2) the location of census blocks that may have been serviced by contaminated water supplies delivered through the water distribution system. To determine the extent and magnitude of contamination within the water distribution system, which consists of more than 1,700 pipeline segments, more than 186 mi of pipes, 9 groundwater extraction wells, and 3 municipal reservoirs, we conducted hydraulic and chemical fate modeling of the network. Flow within each pipe segment and the contaminant concentration at each pipe section and hydrant were simulated. Four simulation scenarios representing pumping conditions for 1970, 1974, 1979, and peak demand periods were conducted for the water distribution system. Results of the simulations were then integrated with characteristics of census subdivisions and demographics for the town of Southington through the use of a GIS. Applying spatial analysis techniques through the use of the GIS enabled us to determine which census blocks were served by contaminated water under the four simulation scenarios, and the spatial distribution and range of contaminant concentrations for the exposed census block areas. Because of the spatial distribution of the wells pumping fresh (uncontaminated) groundwater, the scenario representing peak pumping demand (scenario IV) resulted in fewer people being potentially exposed to contaminants in the water distribution system than did results for scenarios II and III (1974 and 1979 conditions, respectively).

Thus, based on our analysis we have conclude that (1) exposure to VOC contamination can exhibit significant spatial variation from one census block to another; (2) for our study area, the maximum contamination of the extraction wells under conditions of maximum groundwater pumping (peak demand conditions, scenario IV) does not yield the expected maximum spatial distribution of exposed census block areas and population; (3) the use of a computational model to estimate the concentration of contaminated water within each census block provides a more refined approach than applying a commonly used "1-mile radius" approach that may incorrectly identify exposed census block areas and population; (4) hydraulic and chemical fate modeling of water distribution systems, such as the one in our application, cannot be conducted by solving mathematical equations that describe a simplified pipe geometry and network, a rigorous analysis is required; (5) although water from contaminated wells is mixed with water from uncontaminated wells and distributed throughout the water distribution system, only selected pipe sections and hydrants may actually become contaminated; and (6) the use of a computational model provides health scientists and public health professionals with a refined methodology that allows them to quantify areas of past exposure and possible public health concern rigorously.

Codes used in this study are in public domain or readily available through vendors. Readers interested in receiving a more detailed description of these codes may contact authors at the Exposure Dose Reconstruction program at ATSDR.

Acknowledgments

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Trademarks

The use of brand or trade names in this paper is for identification purposes only and does not constitute endorsement by the U.S. government.

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Appendix I

Conversion from English to SI Units and Abbreviations

Listed below are factors to be used for converting from the English units used in the text to S.I. units and the accompanying abbreviations.

Length		
1.0 foot (ft)	=	0.3048 meter (m)
1.0 mile (mi)	=	1.609 kilometers (km)
Area		
1.0 square mile (mi^2)	=	2.590 square kilometers (km^2)
Volume		
1.0 million gallons (Mgal)	=	3.785×10^3 cubic meters (m^3)
		3.785×10^6 liters (L)
Flow		
1.0 gallon per minute (gal/min)	=	6.309×10^{-5} cubic meter per second (m^3/s)
1.0 cubic foot per second (ft^3/s)	=	2.832×10^{-2} cubic meter per second (m^3/s)
Mass		
1.0 pound (lb avoirdupois)	=	0.4536 kilogram (kg)
Concentration		
1 part per billion (ppb)	=	1.0 microgram per liter (µg/L)

Table 1. Simulation scenarios, pumping and chemical parameter values

Scenario Pumping Condition	I 1970	II 1974	III 1979	IV Peak Demand
Groundwater Pumpage, in gallons per minute*				
Well Number 1	391.3	389.3	381.9	466.4
Well Number 2	397.1	115.5	436.7	467.0
Well Number 3	185.8	205.0	383.7	510.7
Well Number 4	576.6	283.2	0.	580.0
Well Number 5	0.	463.0	261.2	518.0
Well Number 6	0.	0.	102.7	103.3
Well Number 7	0.	0.	0.	818.5
Well Number 8	0.	0.	0.	608.2
Well Number 9	0.	0.	289.3	692.2
Total Pumpage	1,550.8	1,456.0	1,855.5	4,764.3
Chemical Concentration, in parts per billion[1]				
Well Number 4				
Total VOCs	6,700.	6,700.	0.	6,700.
TCA	0.	0.	0.	3,500.
TCE	0.	0.	0.	120.
Well Number 5				
Total VOCs	0.	319.4	319.4	319.4
TCA	0.	0.	0.	300.
TCE	0.	0.	0.	4.5
Well Number 6				
Total VOCs	0.	0.	151.	151.
TCA	0.	0.	0.	120.
TCE	0.	0.	0.	0.

*Data from D. Aye, Connecticut Department of Health Services, December 2, 1993.

Table 2. Estimated population exposed to contaminated drinking water, Southington, Connecticut.

		Computational Model, Simulation Approach						1-Mile Radius Approach					
		1970 Data			1990 Data			1970 Data			1990 Data		
Scenario	Pumping Conditions	Census Blocks	Area (mi^2)	Total Population	Census Blocks	Area (mi^2)	Total Population	Census Blocks	Area (mi^2)	Total Population	Census Blocks	Area (mi^2)	Total Population
I	1970	29	2.8	5,628	30	3.1	4,953	57	3.1	8,379	65	3.1	5,537
II	1974	62	8.2	14,188	76	8.7	12,849	147	6.3	18,254	151	6.3	13,720
III	1979	62	8.2	14,188	76	8.7	12,849	147	6.3	18,254	151	6.3	13,720
IV	Peak Demand	66	6.0	13,033	76	6.3	12,784	147	6.3	18,254	151	6.3	13,720

List of Illustrations

Figure 1. Study area location and water distribution system, Southington, Connecticut

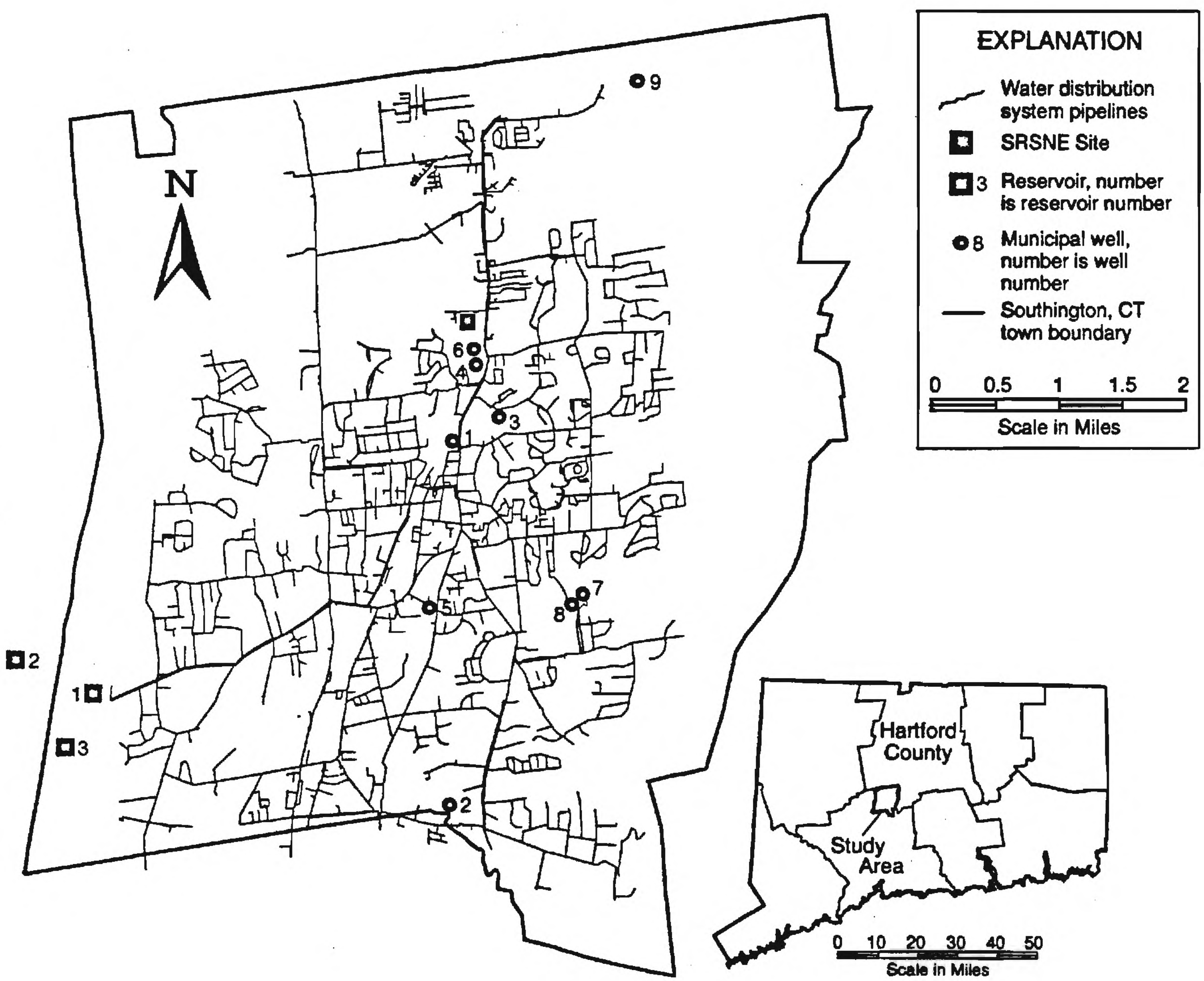


Figure 2. Distribution of pipeline hydrants simulated as being contaminated: (A) Scenario I, (B) Scenario II, (C) Scenario III, and (D) Scenario IV

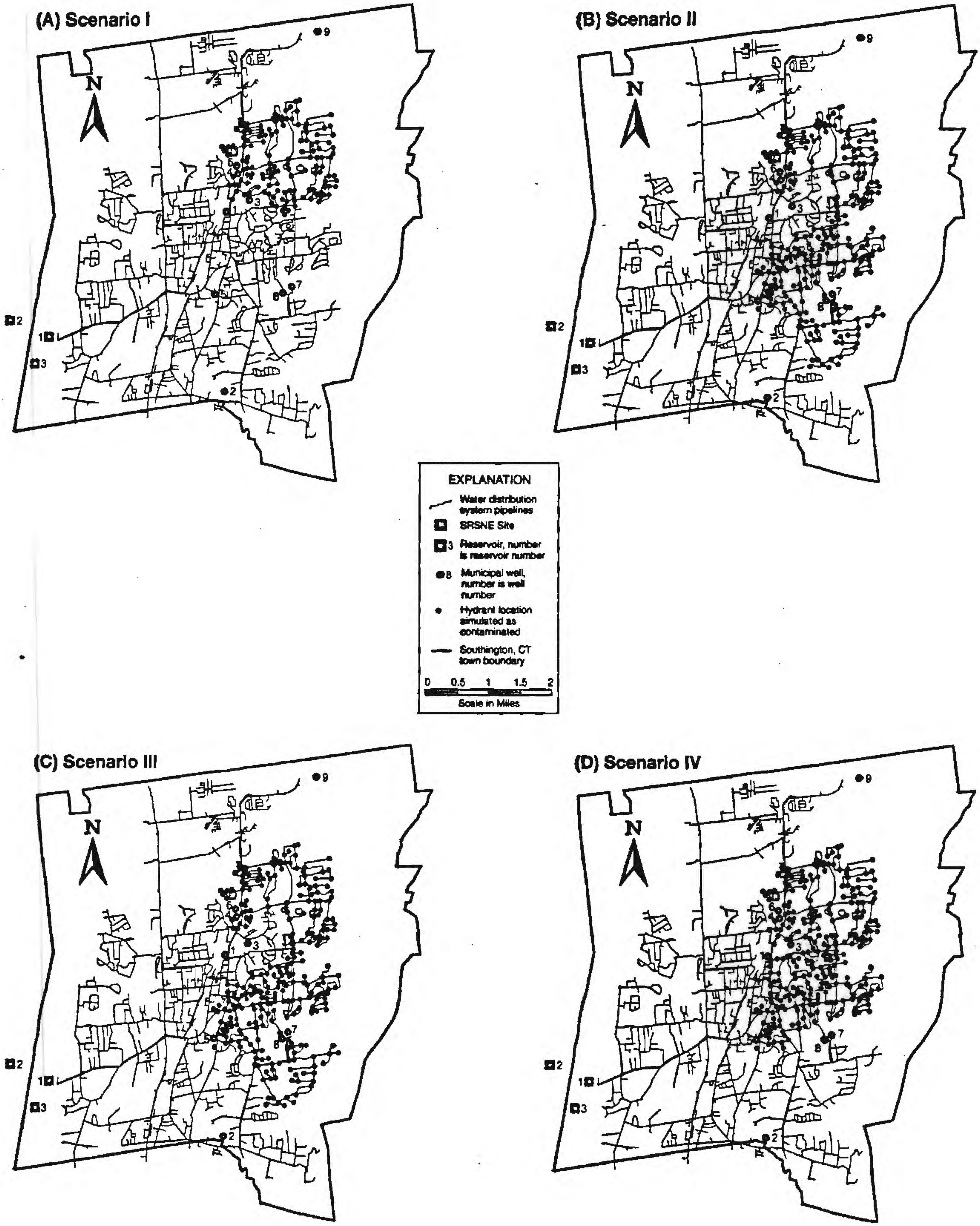


Figure 3A. Spatial distribution of census blocks simulated as being serviced by contaminated water and distribution of maximum total VOC concentration in ppb for Scenario I

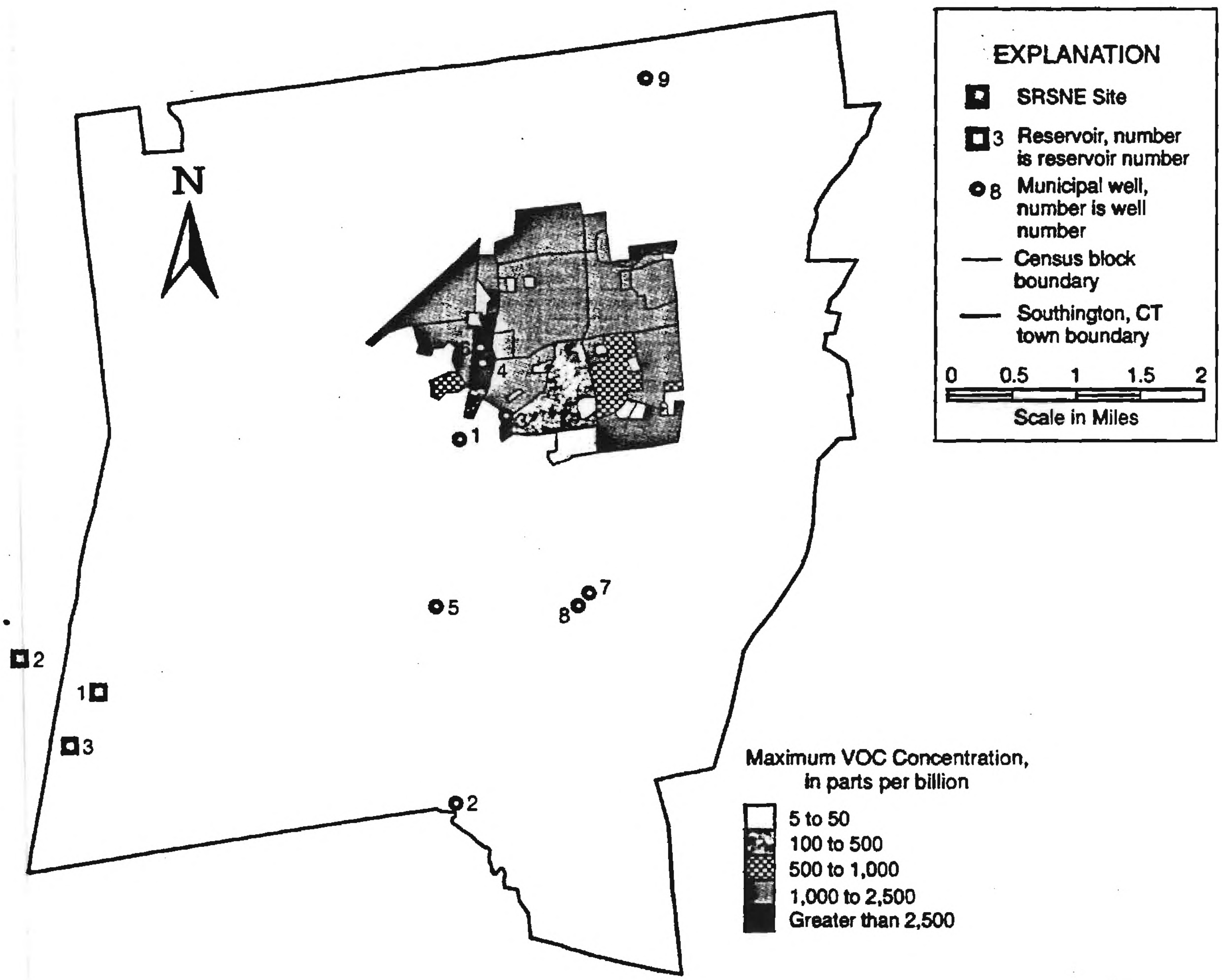


Figure 3B. Spatial distribution of census blocks simulated as being serviced by contaminated water and distribution of maximum total VOC concentration in ppb for Scenario II

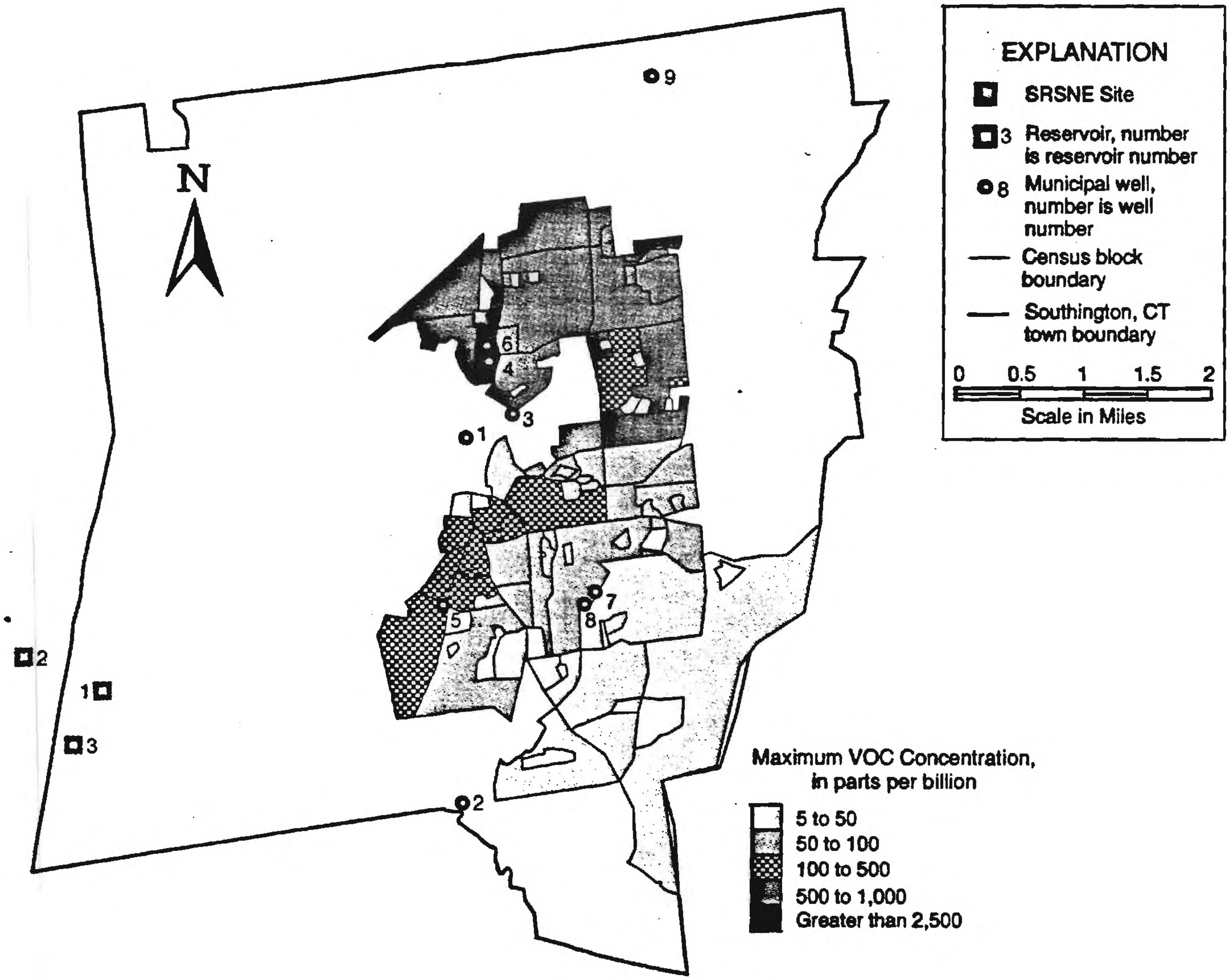


Figure 3C. Spatial distribution of census blocks simulated as being serviced by contaminated water and distribution of maximum total VOC concentration in ppb for Scenario III

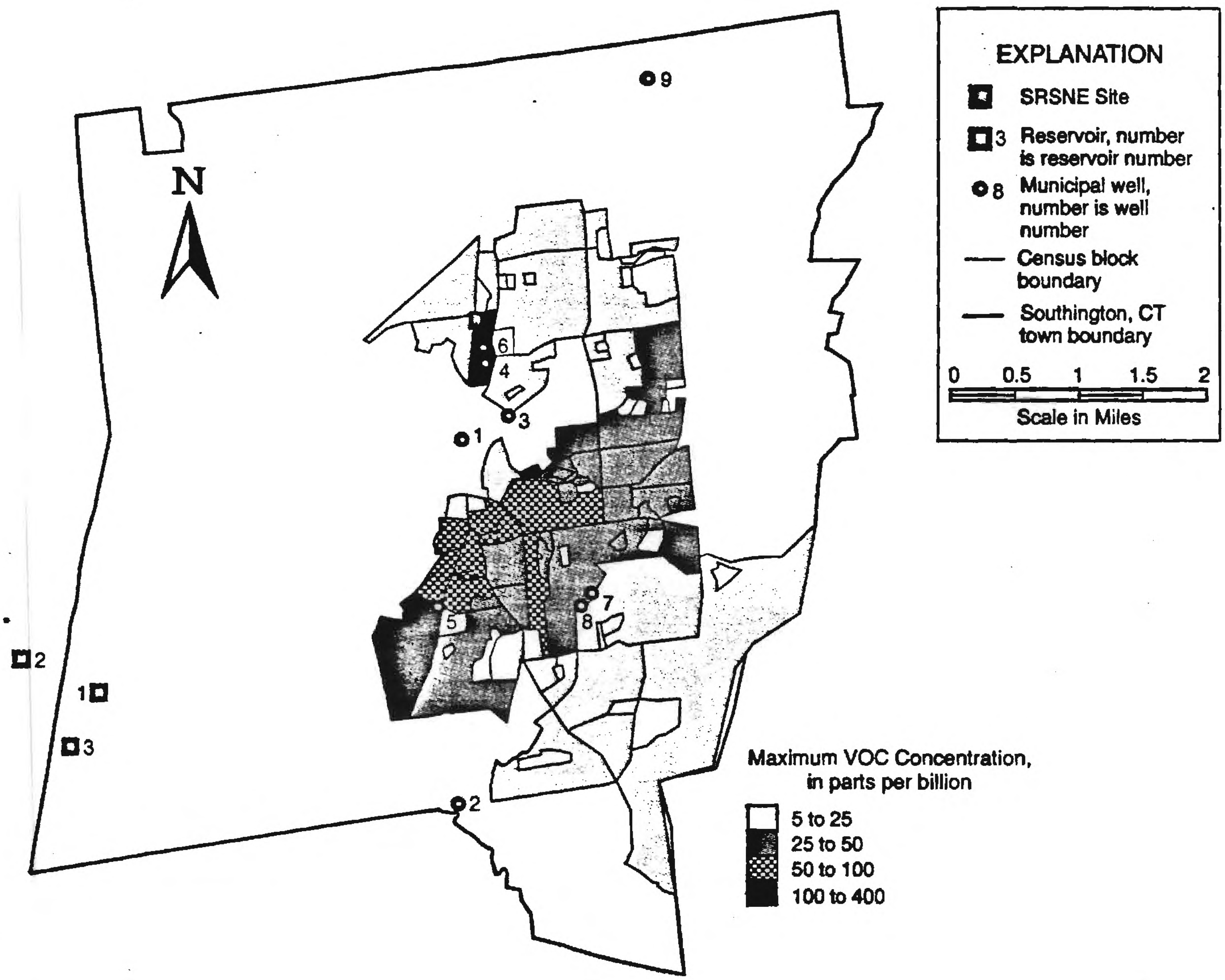


Figure 3D. Spatial distribution of census blocks simulated as being serviced by contaminated water and distribution of maximum total VOC concentration in ppb for Scenario IV

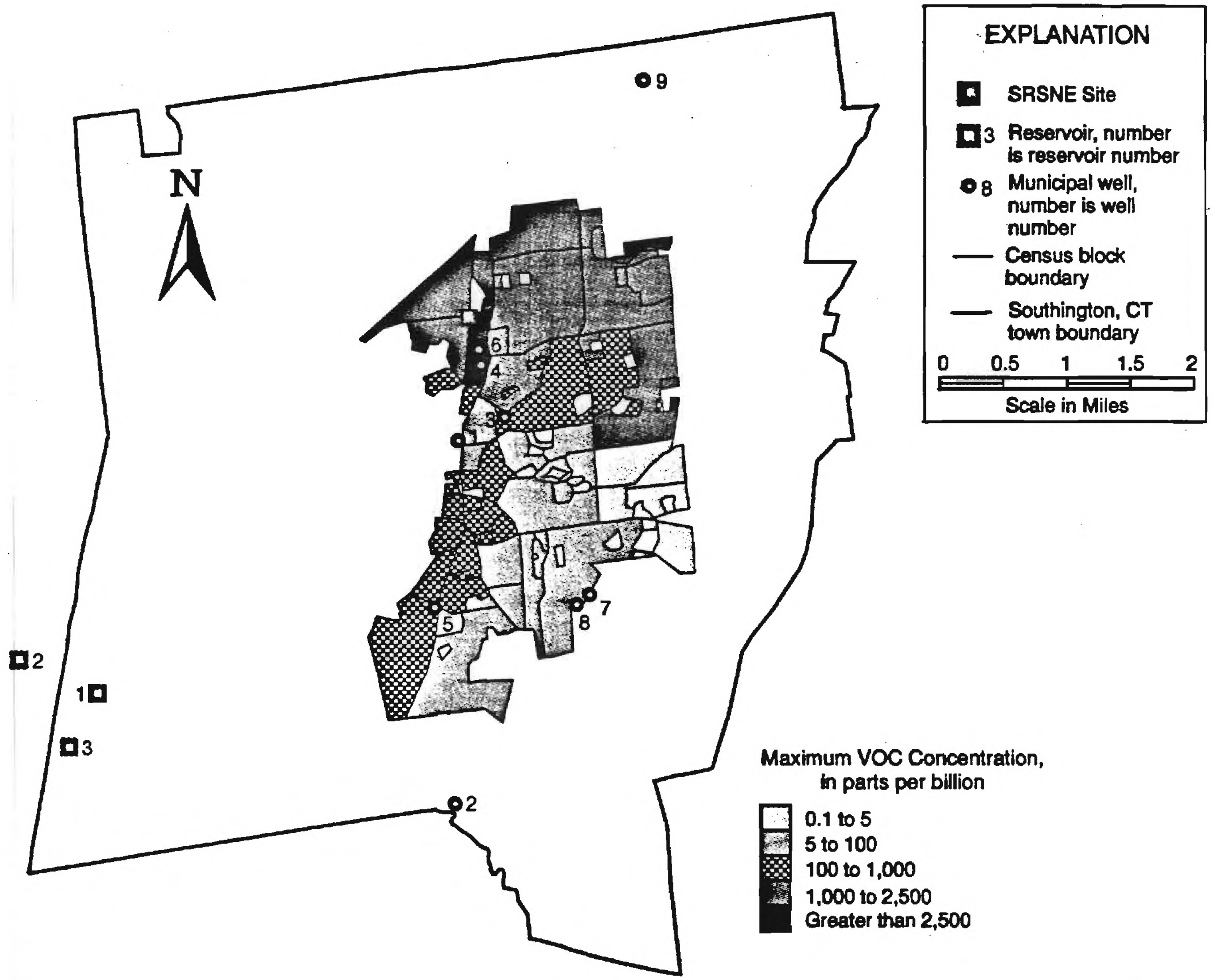
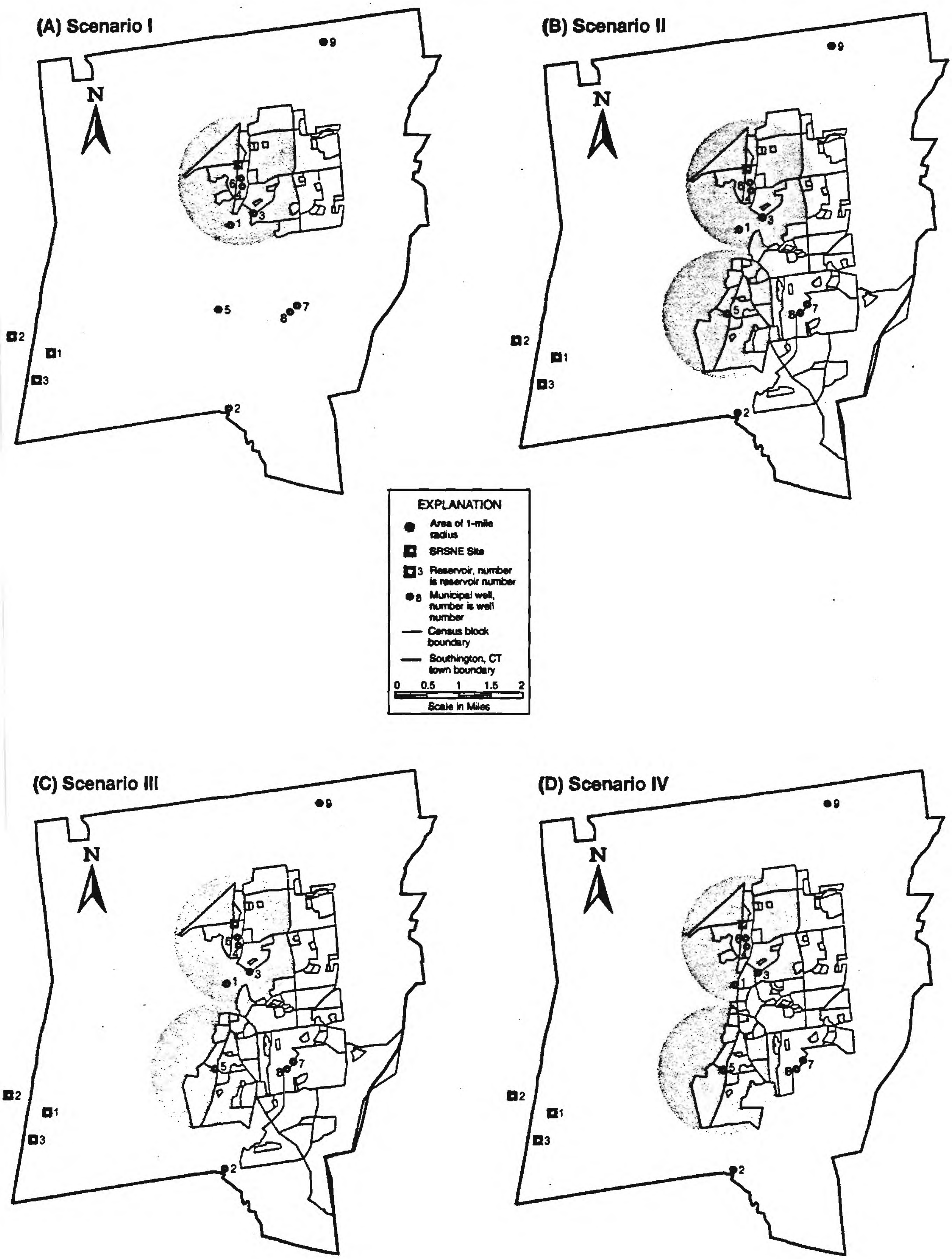


Figure 4. Comparison of census blocks simulated as being serviced by contaminated water with 1-mile radius areas centered at contaminated wells



Evaluation of human exposure to contaminated water supplies using GIS and modeling

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Abstract The Southington, Connecticut, water supply system is characterized by a complex water distribution network. Volatile organic compounds (VOCs) contaminated the underlying groundwater reservoir during the 1970s. This resulted in contamination of the water supply system and exposure of the town's residents to VOCs. A geographic information system (GIS) integrated computational model was applied to the water supply system to characterize and quantify the distribution of VOCs in the pipelines and to estimate the demographic distribution of potential exposure to the town's residents. Based on results from modeling and spatial analysis, we conclude: (1) exposure to VOC contamination may vary significantly from one census block to another even when these census blocks are adjacent to each other within a specified radius; (2) maximum spatial spread of contamination in a water distribution system may not occur under peak demand conditions; and (3) the use of the proposed GIS integrated computational model allows for a more refined and rigorous methodology to estimate census block level contamination for exposure assessment.

INTRODUCTION

Public health professionals continuously seek more refined methods to characterize populations exposed to environmental contamination. Such studies are conducted for a variety of purposes, including: (1) identifying populations at risk from environmental hazards, (2) conducting exposure assessments of sensitive populations, (3) identifying areas for the focus of public health education or community outreach, and (4) identifying target and control populations for health studies. Geographic information systems (GIS), coupled with census information and spatial environmental analysis techniques, offer tools to evaluate such problems.

The Solvents Recovery Services of New England (SRSNE) site, located in the town of Southington, Connecticut (Figure 1), has been listed by the U.S. Environmental Protection Agency (EPA) as a National Priorities List (NPL) site. Groundwater contamination at SRSNE has been documented since 1965. Hydrogeologic investigations and groundwater sampling data suggest that most of the contaminated groundwater in the uppermost aquifer has migrated towards the south and southeast. The Southington Water Company's (SWC) production wells 4, 5 and 6 are located to the south of the SRSNE. Well 4 was installed in 1966, well 6 in 1976, well 5 installed in 1972. Groundwater samples from wells 4, 5, and 6 were identified as contaminated with VOCs and possibly with heavy metals in 1976 and 1977. Water from all three wells was distributed through the town's water supply system, potentially exposing a large population to contaminated water. A more complete description of the site is given in (Aral and Maslia, 1994).

In this paper, we present the methods used to evaluate the distribution of VOCs through the town of Southington's water supply system and the methods used to link these results to exposure analysis via GIS. The proposed approach yielded results that generally contradict a commonly held assumption that all residents within a constant radius of a contaminated water supply well would be exposed to contaminated groundwater extracted from the well (i.e., the "1-mile radius" approximation), or that all residents throughout the entire water distribution system may have been exposed to contaminants that could have exceeded a health criterion. Thus, the methodology described below is valuable for exposure assessment in epidemiologic investigations that attempt to define the public health implications of such problems.

STUDY APPROACH

Assessing the distribution of contaminants in a water distribution system and estimating the population exposed to contaminated water is a complex problem for which the analysis requires a multidisciplinary approach. For a typical study, the following components may be involved: (1) the fate and transport of contaminants in the subsurface and their movement in response to groundwater extraction, (2) the hydraulic characteristics of the water distribution system, (3) contaminant distribution within a water supply network, and (4) spatial analysis with respect to the location of census subdivisions as they relate to the contaminant distribution in the water supply network. In the study presented here our focus area are items (2), (3) and (4). Because of the massive quantity of data required for an analysis of this type, we chose to use a GIS to help manage, manipulate, analyze, and query the data. For this study, we used the GisPlus software package, which runs on a standard IBM compatible personal computer environment (GisPlus, 1992).

HYDRAULIC AND CHEMICAL FATE MODELING

Hydraulic and chemical fate modeling of water distribution systems can be conducted by solving mathematical equations that characterizes the pipe network distribution system. Because of the complex and nonuniform nature of the pipeline network system for the town of Southington (Figure 1), we chose to use the computational program, EPANET, that simulates hydraulic and water quality behavior within generalized water distribution systems. EPANET runs on an IBM/386 and compatible computers under the DOS and WINDOWS™ operating systems which are widely available configurations for desk top computers.

The hydraulic model used by EPANET is an extended period hydraulic simulator that solves the following set of equations for each storage node *s* (tank or reservoir) in the system:

$$\frac{\partial y_s}{\partial t} = \frac{q_s}{A_s} \qquad (1)$$

$$h_s = E_s + y_s \qquad (2)$$

$$q_s = \sum_i q_{is} - \sum_j q_{sj} \tag{3}$$

along with the following equations for each link between nodes *i* and *j* and each node *k*:

$$h_i - h_j = f(q_{ij}) \tag{4}$$

$$\sum_i q_{ik} - \sum_j q_{kj} - Q_k = 0 \tag{5}$$

where the unknown quantities are: y_s = height of water stored at node *s* (ft); q_s = flow into storage node *s* (ft^3/s); q_{ij} = flow in link connecting nodes *i* and *j* (ft^3/s); h_i = hydraulic grade line elevation at node *I* (ft); and the known constants are: A_s = cross-sectional area of storage node *s* (ft); E_s = elevation of node *s* (ft); Q_k = flow consumed (+) or supplied (-) at node *k* (ft^3/s); $f(\cdot)$ = functional relation between head loss and flow in a link. Equation (1) above expresses conservation of water volume at a storage node while Equations (2) and (3) do the same for pipe junctions. Equation (4) represents the energy loss or gain due to flow within a link. For known initial storage node levels y_s at time zero, Equations (4) and (5) are solved for all flows q_{ij} and heads h_i using Equation (3) as a boundary condition.

After the network hydraulic solution is obtained, EPANET's dynamic water quality simulator tracks the fate of a dissolved substance flowing through the network over time. It uses the flow parameters from the hydraulic simulation to solve a conservation of mass equation for the substance within each link connecting nodes *I* and *j*:

$$\frac{\partial C_{ij}}{\partial t} = \frac{q_{ij}}{A_{ij}} \frac{\partial C_{ij}}{\partial x_{ij}} + \theta(C_{ij}) \tag{6}$$

where: C_{ij} = concentration of substance in link *I, j* as a function of distance and time i.e., $C_{ij} = C_{ij}(x_{ij}, t)$, (mass/$ft^3$); x_{ij} = distance along link *I, j* (ft); q_{ij} = flow rate in link *I, j* at time *t* (ft^3/s); A_{ij} = cross-sectional area of link *i, j* (ft^2); $\theta(C_{ij})$ = rate of reaction of constituent within link *i, j* (mass/ft^3/day).

Further details of the program may be found in Rossman (1994) and Rossman and Clark (1994).

Configuration of the water distribution system (Figure 1) and data pertaining to the physical characteristics of pipes (length, diameter, resistance coefficient, hydraulic grade line, location of pipe junctions, elevation of pipe junctions, and water demand) were obtained from information supplied by the Connecticut Department of Health Services (CDHS) and the SWC.

The SWC obtains its water supply by pumping nine municipal wells that extract groundwater at varying rates. The water extracted by these wells is then pumped into the distribution system. Thus, when wells 4, 5, and 6 became contaminated with VOCs, the contaminated groundwater was mixed with water pumped from other wells and distributed within the water distribution system. For the purposes of our analysis, we conducted four different simulations to represent as closely as possible (based on available data) the configuration of the water distribution system and operation of the pumping wells during the period of contamination. These simulations represent the following pumping configurations and contaminated wells (Table 1): (1) Scenario I, 1970 conditions, well 4 contaminated; (2) Scenario II, 1974 conditions, wells 4 and 5 contaminated; (3) Scenario III, 1979 conditions, wells 5 and 6 contaminated; and (4) Scenario IV, maximum pumping (peak demand) conditions, wells 4, 5, and 6 contaminated.

APPLICATION OF GIS

We used the data described above to run the computational model for each of the four scenarios. The digital output from the model was retrieved and placed into databases for use with the GIS via specialized interfacing routines. These databases were then transformed into point and line coverages for use as overlays with the GIS. The coverages contain spatial information and attribute characteristics about pipe and hydrant locations and elevations, water demand, hydraulic grade, pressure, and chemical concentration at each junction and pipe link. For each simulation scenario, the pipe hydrants that were simulated as being contaminated were selected by use of the querying, selection, and aggregation capabilities of the GIS. Figures 2A through 2D show the distribution and location of pipe hydrants (black dots) that were simulated as being contaminated for Scenarios I, II, III, and IV, respectively.

These simulations were used to determine the spatial relationship between the location of contaminated hydrants (Figure 2) and the location of census subdivisions where the pipe junctions are located. We also determined the distribution of contaminants within the census subdivision areas served by the contaminated distribution system. In this article, we present results solely for total VOCs, although our study contained analyses for other contaminants (Aral and Maslia, 1994).

The United States is subdivided into political (e.g., county) and census statistical (e.g., tract, block group, and block) geographic areas for which population data are tabulated. The geographic census block data are available in digital format on CD-ROM through the Bureau of the Census' TIGER/Line files (Washington, 1994). To begin our analysis, we used the querying and aggregating operations of our GIS and compiled all census block areas that contained pipe hydrants with simulated contaminant concentrations greater than 0 ppb. During these analyses, we aggregated contaminant levels for each census block by minimum, maximum, and mean values. The results of these analyses, which are contaminated census block areas, are shown in Figures 3A-3D for simulation scenarios I (1970 conditions), II (1974 conditions), III (1979 conditions), and IV (peak demand conditions), respectively. In Figure 3, the shaded areas indicate the range of maximum concentration of total VOCs in ppb for the census block areas served by the contaminated pipelines. Table 2 lists the number of census blocks estimated to have been served by contaminated water from the water distribution system and the total population for those census blocks.

To compare our results with results from an approach commonly used to estimate exposure within a 1-mile radius of a contaminated site, we again used the spatial analysis capability of the GIS. By overlaying the area derived from a 1-mile radius around the contaminated wells, we computed estimates of the census block areas and population exposed to contaminated water for the four simulation scenarios. Table 2 lists the census block areas and estimated population exposed to contaminated water derived by this method. Additionally, we compared the census blocks estimated to have been served by contaminated pipelines as previously described (Figure 3) with the 1-mile radii circles around the contaminated wells for each simulation scenario as shown in F.igures 4A through 4D.

DISCUSSION OF RESULTS AND CONCLUSIONS

To estimate the population that may have been exposed to contaminated municipal water supplies in Southington, Connecticut, we conducted four simulations of the water distribution system. The simulations represented pumping conditions for 1970, 1974, 1979, and peak demand based on data supplied by the CDHS. Results of these simulations indicate that spatial distribution of contamination is sensitive to and may be a function of the location and number of wells that are pumping. For example, in scenario I, only four wells are pumping and only well 4 is contaminated (Table 1). This results in the smallest area of contamination of the four simulations (Figures 2A and 3A). However, maximum pumping demand, scenario IV, with all of the wells pumping and wells 4, 5, and 6 contaminated (Table 1), does not produce the largest area of exposure when compared with scenarios II and III (compare Figures 3B and 3C with Figure 3D). Analysis of the hydraulics of the water distribution system for each simulation scenario will lead to an explanation of this seeming discrepancy. In scenarios II and III, wells 7 and 8 are not in service (Table 1); these wells are located in the southeastern part of Southington (Figure 2). In order to supply the demand for water to that part of Southington, the water distribution system must deliver water from the more western and northern parts of the distribution system. Thus, contaminated water from wells 4, 5, or 6 is routed to the southeastern part of Southington. On the other hand, when all wells are pumping (scenario IV, Table 1), wells 7 and 8 are used to satisfy the water demand for the southeastern part of town. Because these wells are providing water that is not contaminated, and the demand in the southeastern part of town is completely satisfied, there is no need for the water distribution system to deliver contaminated water to the western and northern parts of the town.

Results of simulation scenarios II and III indicate that the same census blocks are exposed for each scenario, although pumping and contamination conditions vary (Figures 3B and 3C). The distribution of exposed census blocks should be nearly the same because wells 4 and 6 are located within a few feet of each other. However, our analysis shows that there is a significant difference in the contaminant concentration values computed for each census block based on the two scenarios (compare Figures 3B and 3C). This result could have an important impact on the design of exposure assessment studies and subsequent public health evaluations because of the difference in contaminant levels to which the population was exposed.

Our analysis also demonstrates the inadequacy of a common approach used to estimate exposed populations by drawing a circle of a constant radius around the source of contamination. Our results indicate that the census blocks served by contaminated water are generally to the east of the contaminated wells (Figures 2 and 3). This is because of the hydraulic characteristics of the water distribution system, which can only be determined through the use of the computational program previously described. Had we used the "1-mile radius" approach centered at the contaminated wells, we would have concluded that the census blocks to the west of the wells were also serviced by contaminated water distribution system pipes. This approach, therefore, would have incorrectly identified a population exposed to contaminated water when in fact they had not been exposed.

A final observation that can be made from our analysis is, that when applying the "1-mile radius" approach for estimating exposure, it is generally assumed that the concentration of the contaminated water within the 1-mile radius area is a constant value. Results that we obtained by integrating the water distribution system model with the GIS indicate that there is a noticeable spatial variation in levels of contamination within the exposed census block areas (Figure 3).

The methodology and analysis presented in this paper have provided us with the ability to estimate; (1) the extent and location of the water supply system that distributed groundwater contaminated with total VOCs, and (2) the location of census blocks that may have been serviced by contaminated water supplies delivered through the water distribution system. Thus, based on our analysis we have conclude that: (1) exposure to VOC contamination can exhibit significant spatial variation from one census block to another, for our study area, the maximum contamination of the extraction wells under conditions of maximum groundwater pumping (peak demand conditions, scenario

IV) does not yield the expected maximum spatial distribution of exposed census block areas and population; (2) the use of a computational model integrated with demographic and spatial analyses via a GIS to estimate the concentration of contaminated water within each census block provides a more refined approach than applying a commonly used "1-mile radius" approach that may incorrectly identify exposed census block areas and population; and (3) the ability to integrate water distribution system modeling and demographic analysis via a GIS to determine human exposure provides health scientists and public health professionals with a refined methodology that allows them to quantify areas of past exposure and possible public health concern more rigorously.

Acknowledgments The research described in this paper was supported by Cooperative Agreement award number U50/ATU499828-01 for the Research Program for Exposure-Dose Reconstruction between the Agency for Toxic Substances and Disease Registry (ATSDR) and the Georgia Institute of Technology. The authors would like to express their appreciation to Robert C. Williams, Director, Division of Health Assessment and Consultation, ATSDR, and Barry L. Johnson, Assistant Administrator, ATSDR, for their continued support of the project.

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Washington, DC: Bureau of the Census, 1991.

Table 1. Simulation scenarios, pumping and chemical parameter values

Scenario	I	II	III	IV
Pumping Condition (gallons per min)	1970	1974	1979	Peak Demand
Well Number 1	391.3	389.3	381.9	466.4
Well Number 2	397.1	115.5	436.7	467.0
Well Number 3	185.8	205.0	383.7	510.7
Well Number 4	576.6	283.2	0.	580.0
Well Number 5	0.	463.0	261.2	518.0
Well Number 6	0.	0.	102.7	103.3
Well Number 7	0.	0.	0.	818.5
Well Number 8	0.	0.	0.	608.2
Well Number 9	0.	0.	289.3	692.2
Total Pumpage	1,550.8	1,456.0	1,855.5	4,764.3
Chemical Concentration, in parts per billion				
Well Number 4 Total VOCs	6,700.	6,700.	0.	6,700.
Well Number 5 Total VOCs	0.	319.4	319.4	319.4
Well Number 6 Total VOCs	0.	0.	151.	151.

*Data from D. Aye, Connecticut Department of Health Services, December 2, 1993.

Table 2. Estimated population exposed to contaminated drinking water, Southington, Connecticut.

		Computational Model, Simulation Approach						1-Mile Radius Approach					
		1970 Data			1990 Data			1970 Data			1990 Data		
Scenario	Pumping Conditions	Census Blocks	Area (mi^2)	Total Population	Census Blocks	Area (mi^2)	Total Population	Census Blocks	Area (mi^2)	Total Population	Census Blocks	Area (mi^2)	Total Population
I	1970	29	2.8	5,628	30	3.1	4,953	57	3.1	8,379	65	3.1	5,537
II	1974	62	8.2	14,188	76	8.7	12,849	147	6.3	18,254	151	6.3	13,720
III	1979	62	8.2	14,188	76	8.7	12,849	147	6.3	18,254	151	6.3	13,720
IV	Peak Demand	66	6.0	13,033	76	6.3	12,784	147	6.3	18,254	151	6.3	13,720

List of Illustrations

E-20-W89
#1

GEORGIA TECH RESEARCH CORPORATION

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
PROGRAM INITIATION DIVISION
ATLANTA, GEORGIA 30332-0420
USA

Telex: 542507 GTRC OCA ATL
Fax: (404) 894-6956

Phone: (404) 894-4817

Refer to: JG/02.108.002.96.006

30 May 1996

Centers for Disease Control and Prevention
Agency for Toxic Substances and Disease Registry
Room 321, MS (E-13)
255 E. Paces Ferry Road
Atlanta, GA 30305

Attention: Ms. Maggie Slay
Grants Management Specialist

Subject: Research Proposal Entitled "Research Program for Exposure-Dose Reconstruction"

Reference: U61/ATU499828-03

Dear Ms. Slay:

The GEORGIA TECH RESEARCH CORPORATION desires to submit for your consideration the subject proposal prepared by Dr. Mustafa M. Aral, School of Civil and Environmental Engineering, Georgia Institute of Technology.

A description of the research program, the time required and program costs are included in the proposal. Should additional information be desired, please do not hesitate to contact Dr. Aral at 404/894-2243 regarding technical matters or the undersigned at 404/894-4817 for administrative concerns.

We appreciate the opportunity of submitting this proposal and look forward to working with you on this project.

Sincerely,

Janis L. Goddard
Contracting Officer

Addressee: Three copies
Enclosure: Proposal - Three copies

OMB Approval No. 0348-0043

APPLICATION FOR FEDERAL ASSISTANCE

2. DATE SUBMITTED May 24, 1996

Applicant Identifier

1. TYPE OF SUBMISSION:

Application
- ☐ Construction
- XXX Non-Construction

Preapplication
- ☐ Construction
- ☐ Non-Construction

3. DATE RECEIVED BY STATE

State Application Identifier

4. DATE RECEIVED BY FEDERAL AGENCY

Federal Identifier

5. APPLICANT INFORMATION

Legal Name: GEORGIA TECH RESEARCH CORP.

Organizational Unit: School of Civil and Env. Eng.

Address (give city, county, state, and zip code):
Office of Contracts Adm.
Georgia Institute of Tech.
Atlanta, Fulton Georgia 30332-0420

Name and telephone number of the person to be contacted on matters involving this application (give area code)
Dr. Mustafa M. Aral (404) 894 2243

6. EMPLOYER IDENTIFICATION NUMBER (EIN):

7. TYPE OF APPLICANT: (enter appropriate letter in box) I

A. State
B. County
C. Municipal
D. Township
E. Interstate
F. Intermunicipal
G. Special District
H. Independent School Dist.
I. State Controlled Institution of Higher Learning
J. Private University
K. Indian Tribe
L. Individual
M. Profit Organization
N. Other (Specify) ____

8. TYPE OF APPLICATION:

☐ New XX Continuation ☐ Revision

If Revision, enter appropriate letter(s) in box(es): ☐ ☐

A. Increase Award B. Decrease Award C. Increase Duration
D. Decrease Duration Other (specify):

9. NAME OF FEDERAL AGENCY:

ATSDR-US Department of Health and Human Serv.

10. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER:

TITLE: Program Announcement no 326

11. DESCRIPTIVE TITLE OF APPLICANT'S PROJECT:

Research Program on Exposure-Dose Reconstruction

12. AREAS AFFECTED BY PROJECT (cities, counties, states, etc.):

NONE - General Mothod Development

13. PROPOSED PROJECT:

Start Date	Ending Date
Sept, 1993	Sept, 1997

14. CONGRESSIONAL DISTRICTS OF:

a. Applicant	b. Project
V	GENERAL

15. ESTIMATED FUNDING:

a. Federal	$ 309,211	.00
b. Applicant	$ ----	.00
c. State	$ 29,447	.00
d. Local	$ ----	.00
e. Other	$ ----	.00
f. Program Income	$ ----	.00
g. TOTAL	$ 338,658	.00

16. IS APPLICATION SUBJECT TO REVIEW BY STATE EXECUTIVE ORDER 12372 PROCESS?

a. YES THIS PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON

DATE ____

b. NO XXX PROGRAM IS NOT COVERED BY E.O. 12372

☐ OR PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW

17. IS THE APPLICANT DELINQUENT ON ANY FEDERAL DEBT?

☐ Yes If "Yes," attach an explanation. XXX No

18. TO THE BEST OF MY KNOWLEDGE AND BELIEF, ALL DATA IN THIS APPLICATION/PREAPPLICATION ARE TRUE AND CORRECT, THE DOCUMENT HAS BEEN DULY AUTHORIZED BY THE GOVERNING BODY OF THE APPLICANT AND THE APPLICANT WILL COMPLY WITH THE ATTACHED ASSURANCES IF THE ASSISTANCE IS AWARDED

a. Typed Name of Authorized Representative: Janis Goddard

b. Title: Contracting Officer

c. Telephone number: 404-894-4817

d. Signature of Authorized Representative

e. Date Signed: 5/30/96

Previous Editions Not Usable

Standard Form 424 (REV 4-88)
Prescribed by OMB Circular A-102

SECTION C - NON-FEDERAL RESOURCES

(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) TOTALS
8. ATSDR-U61/ATU499828-03 Continuation Project	$ 0.00	$ 29,447.00	$ 14,609.00	$44,056.00
9.			Unobligated funds	
10.				
11.				
12. TOTALS (sum of lines 8 and 11)	$ 0.00	$ 29,447.00	$ 14,609.00	$ 44,056.00

SECTION D - FORECASTED CASH NEEDS

	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$ 309,211.00	$77,302.00	$ 77,302.00	$ 77,302.00	$ 77,305.00
14. Nonfederal	29,447.00	9,815.00	9,815.00	9,817.00	----
15. TOTAL (sum of lines 13 and 14)	$ 338,658.00	$87,117.00	$ 87,117.00	$87,119.00	$ 77,305.00

SECTION E - BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT

(a) Grant Program	FUTURE FUNDING PERIODS (Years)			
	(b) First	(c) Second	(d) Third	(e) Fourth
16.	$300,000.00	$	$	$
17.				
18.				
19.				
20. TOTALS (sum of lines 16 -19)	$300,000.00	$	$	$

SECTION F - OTHER BUDGET INFORMATION

(Attach additional Sheets if Necessary)

21. Direct Charges:	22. Indirect Charges: 43%

23. Remarks

ASSURANCES — CONSTRUCTION PROGRAMS

Note: Certain of these assurances may not be applicable to your project or program, If you have questions, please contact the Awarding Agency. Further, certain federal assistance awarding agencies may require applicants to certify to additional assurances. If such is the case, you will be notified.

As the duly authorized representative of the applicant I certify that the applicant:

1. Has the legal authority to apply for Federal assistance, and the institutional, managerial and financial capability (including funds sufficient to pay the non-Federal share of project costs) to ensure proper planning, management and completion of the project described in this application.

2. Will give the awarding agency, the Comptroller General of the United States, and if appropriate, the State, through any authorized representative, access to and the right to examine all records, books, papers, or documents related to the assistance; and will establish a proper accounting system in accordance with generally accepted accounting standards or agency directives.

3. Will not dispose of, modify the use of, or change the terms of the real property title, or other interest in the site and facilities without permission and instructions from the awarding agency. Will record the Federal interest in the title of real property in accordance with awarding agency directives and will include a covenant in the title of real property acquired in whole or in part with Federal assistance funds to assure nondiscrimination during the useful life of the project.

4. Will comply with the requirements of the assistance awarding agency with regard to the drafting, review and approval of construction plans and specifications.

5. Will provide and maintain competent and adequate engineering supervision at the construction site to ensure that the complete work conforms with the approved plans and specifications and will furnish progress reports and such other information as may be required by the assistance awarding agency or State.

6. Will initiate and complete the work within the applicable time frame after receipt of approval of the awarding agency.

7. Will establish safeguards to prohibit employees from using their positions for a purpose that constitutes or presents the appearance of personal or organizational conflict of interest, or personal gain.

8. Will comply with the Intergovernmental Personnel Act of 1970 (42 U.S.C. §§ 4728-4763) relating to prescribed standards for merit systems for programs funded under one of the nineteen statutes or regulations specified in Appendix A of OPM's Standards for a Merit System of Personnel Administration (5 C.F.R. 900, Subpart F).

9. Will comply with the Lead-Based Paint Poisoning Prevention Act (42 U.S.C. §§ 4801 et seq.) which prohibits the use of lead based paint in construction or rehabilitation of residence structures.

10. Will comply with all Federal statues relating to non-discrimination. These include but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352) which prohibits discrimination on the basis of race, color or national origin; (b) Title IX of the Education Amendments of 1972, as amended (20 U.S.C. §§ 1681-1683, and 1685-1686) which prohibits discrimination on the basis of sex; (c) Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S.C. § 794) which prohibit discrimination of the basis of handicaps; (d) the Age Discrimination Act of 1975, as amended (42 U.S.C. §§ 6101-6107) which prohibits discrimination on the basis of age; (e) the Drug Abuse Office and Treatment Act of 1972 (P.L. 93-255), as amended, relating to non-discrimination on the basis of drug abuse; (f) the Comprehensive Alcohol Abuse and Alcoholism Prevention, Treatment and Rehabilitation Act of 1970 (P.L. 91-616), as amended, relating to nondiscrimination on the basis of alcohol abuse or alcoholism; (g) §§ 523 and 527 of the Public Health Service Act of 1912 (42 U.S.C. 290 dd-3 and 290 ee-3), as amended, relating to confidentiality of alcohol and drug abuse patient records; (h) Title VIII of the Civil Rights Act of 1968 (42 U.S.C. § 3601 et seq.), as amended, relating to non-discrimination in the sale, rental or financing of housing; (i) any other non-discrimination provisions in the specific statute(s) under which application for Federal assistance is being made, and (j) the requirements on any other non-discrimination Statute(s) which may apply to the application.

OMB Approval No. 0937-0189
Expiration Date: March 31, 1995

CERTIFICATIONS

1. CERTIFICATION REGARDING DEBARMENT AND SUSPENSION

The undersigned (authorized official signing for the applicant organization) certifies to the best of his or her knowledge and belief, that the applicant, defined as the primary participant in accordance with 45 CFR Part 76, and its principals:

(a) are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal Department or agency;
(b) have not within a 3-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;
(c) are not presently indicted or otherwise criminally or civilly charged by a governmental entity (Federal, State, or local) with commission of any of the offenses enumerated in paragraph (b) of this certification; and
(d) have not within a 3-year period preceding this application/proposal had one or more public transactions (Federal, State, or local) terminated for cause or default.

Should the applicant not be able to provide this certification, an explanation as to why should be placed after the assurances page in the application package.

The applicant agrees by submitting this proposal that it will include, without modification, the clause titled "Certification Regarding Debarment, Suspension, Ineligibility, and Voluntary Exclusion—Lower Tier Covered Transaction" (Appendix B to 45 CFR Part 76) in all lower tier covered transactions (i.e., transactions with subgrantees and/or contractors) and in all solicitations for lower tier covered transactions.

2. CERTIFICATION REGARDING DRUG-FREE WORKPLACE REQUIREMENTS

The undersigned (authorized official signing for the applicant organization) certifies that it will provide a drug-free workplace in accordance with 45 CFR Part 76 by:

(a) Publishing a statement notifying employees that the unlawful manufacture, distribution, dispensing, possession or use of a controlled substance is prohibited in the grantee's workplace and specifying the actions that will be taken against employees for violation of such prohibition;
(b) Establishing a drug-free awareness program to inform employees about—
    (1) The dangers of drug abuse in the workplace;
    (2) The grantee's policy of maintaining a drug-free workplace;
    (3) Any available drug counseling, rehabilitation, and employee assistance programs; and
    (4) The penalties that may be imposed upon employees for drug abuse violations occurring in the workplace;
(c) Making it a requirement that each employee to be engaged in the performance of the grant be given a copy of the statement required by paragraph (a) above;
(d) Notifying the employee in the statement required by paragraph (a), above, that, as a condition of employment under the grant, the employee will—
    (1) Abide by the terms of the statement; and
    (2) Notify the employer of any criminal drug statute conviction for a violation occurring in the workplace no later than five days after such conviction;
(e) Notifying the agency within ten days after receiving notice under subparagraph (d)(2), above, from an employee or otherwise receiving actual notice of such conviction;
(f) Taking one of the following actions, within 30 days of receiving notice under subparagraph (d)(2), above, with respect to any employee who is so convicted—

Annual Progress Report for Project Period 3
and
Application for Extension for Project Year: 4

RESEARCH PROGRAM FOR EXPOSURE-DOSE RECONSTRUCTION

Submitted to:

Agency for Toxic Substances and Disease Registry (ATSDR)

Project Officer: Allan S. Susten, Ph.D. (DHAC, MS E-32)
Technical Project Officer: Morris L. Maslia, P.E. (DHAC, MS E-32)

Centers for Disease Control and Prevention and ATSDR
Award Reference No. U61/ATU499828-03

Submitted by:

Mustafa M. Aral, Ph.D.

Principal Investigator
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

May 27, 1996

TABLE OF CONTENTS

1. REVIEW OF RESEARCH ACTIVITIES FOR PROJECT YEAR 3

The cooperative agreement on Exposure-Dose Reconstruction Project (EDRP) was awarded to Dr. M. M. Aral, School of Civil and Environmental Engineering, Georgia Institute of Technology, towards the end of September 1993. Since then our efforts focused on several tasks of the research program in order to start the project in a most efficient and cost effective manner. We have successfully completed the first project period during the 1993-1994 and the second project period during the 1994-1995 academic year. The progress made during the first and second years of the research program was submitted to ATSDR, USDHHS, in Annual Progress Reports on January, 1995 and 1996. We are now in the third project period (1995-1996) of the research program and this proposal is submitted to ATSDR for the fourth project period (1996-1997). A description of administrative efforts, research activities and the progress made in each activity during the third year of the research program are described in this report. This report also includes the budget and non competitive Application for Extension of the Project to the Fourth Project Period.

- **Purchase of the computational equipment**:

  The third phase of the purchase of the computer equipment necessary for the project has been completed. We anticipate that we will be adding to this equipment throughout the duration of the project as future needs arise. The equipment purchased for the Exposure Dose Reconstruction Research program is compatible with the present standards and other computational equipment used by ATSDR. With this equipment, direct communication between ATSDR and Ga. Tech has been established through Ethernet communication platform. It is also anticipated that the compatibility established between the equipment at both sites will enhance the technology transfer phase of the research program which is anticipated to occur during later stages of the research program.

- **Development of the analytical framework for the prediction of contaminant migration scenarios in multiple exposure pathways**:

  It is anticipated that the contaminant migration analysis (the forward pathway calculation environment) will include several analytical tools to evaluate the contaminant concentration levels in multiple and interactive pathways. These pathways, at a minimum, will include the following:

  (I) air pathway;
  (ii) ground-water pathway;
  (iii) surface water pathway; and,
  (iv) animals/plants pathway.

  According to the proposed schedule of the research program, the analytic tools for exposure assessment in these pathways will be developed throughout the duration of the project. During the first project year, it was extremely important to conceptualize the overall system and develop a unified analytical structure and a user friendly framework for this computational environment. As parts of the overall system are developed, and several analytical tools are put together, this unified structure will provide the framework necessary for a user friendly computational environment. This approach was selected to minimize the revisions that will be necessary during the later stages of the research program. Major portion of this task was completed during the first project year. Although this software development effort may not be in its final form, the initial computational tool developed for the ground-water pathway and submitted to ATSDR during the first project period, indicate our line of taught for the general computational environment we are developing in this effort. During the second and third project periods, the first year's initial effort was modified significantly resulting in a major upgrade of the overall product. The new version of the software was submitted to ATSDR for beta testing during April 1996 (ACTS version 2.7). This version of the software is now more user friendly and more computationally efficient. In this tool several analytic solutions for the ground-water pathway and also the air pathway was developed along with a graphical and text output format interphase which may be used to interpret the results. This version of the software now also includes the Monte Carlo simulations for the air pathway and the groundwater pathway analysis as described in more detail below. This is an essential component of for these pathways since the inherent uncertainties of the computations in the air and groundwater pathway is much more pronounced. This software will be updated throughout the remaining part of the third and fourth project periods to include analytical tools for other pathways mentioned above as well as other revisions that may be recommended by ATSDR. In it's present form the computational tool submitted to ATSDR can be used to evaluate concentration distributions in site specific cases for the ground-water pathway and air pathway including Monte Carlo computations for each pathway. This software can be installed in ATSDR's network system for immediate access by all health professionals. At the present this computational tool is tested and used successfully in several site specific applications by ATSDR professionals.

- **Monte Carlo simulations in analytic contaminant migration analysis**

As was proposed in our first year progress report, an important component of the second project period effort was the incorporation of evaluation of the uncertainties involved in analytic contaminant migration simulations. Evaluation of the effect of these uncertainties on the numerical results generated can be accomplished using Monte Carlo methods.

Implementation of analytical tools in all pathways requires a number of input parameters including source-specific, media-specific, and chemical-specific variables. Typically, the values of these parameters are not known exactly due to measurement errors and/or inherent spatial and temporal variability. Therefore, it is often more appropriate to express these parameter values in terms of a probability distribution rather than a single deterministic value and use an uncertainty propagation model to assess the effect of the variability on the output of the models. Most suitable method that can be employed for this purpose is the Monte Carlo method. Based on the principles of this approach, the following procedure is incorporated to the software developed for ATSDR.

Whatever the source of the parameter uncertainty, the uncertainty can be quantified using a cumulative probability distribution. Thus, for each parameter to be analyzed as an uncertain variable, the user may select and assign a probability distribution (normal, log normal, uniform, exponential, triangular) for the variable and specify the parameters that describe the distribution. In Monte Carlo simulations, data sets randomly generated from these distributions form the basis of the data sets that will be used in deterministic models which in turn will generate a population of model outputs. This series of outputs can than be analyzed to yield a cumulative probability distribution of expected model results. This distribution quantitatively describes the uncertainty in the model output and can be used in decision making.

During the second project year, considerable effort was devoted to introduce Monte Carlo simulation tools into the overall computational framework developed in the first project year. With this component added to the system, users will have the choice to select between direct calculations (deterministic mode computations) and Monte Carlo simulations in pathway analysis exercises based on the confidence they have on the parameters they are using in their applications. With the addition of Monte Carlo methods, the flexibility and reliability of the computational system is improved and the applicability of the overall system to cases with uncertainty in input data bases is enhanced. During the second project period the Monte Carlo simulation tools were included into the air pathway calculations. During the third project period the Monte Carlo Simulations were included to the groundwater pathway which was developed as a deterministic computational tool during the first project period. During the fourth project period this model will also be implemented in surface water and animals and plants pathway models.

- **An application study for contaminant transport analysis in pipe network systems and GIS based evaluation of exposure assessment for a site specific case:**

ATSDR and the Connecticut Department of Health Services (CDHS) has collaborated in a study of cancer incidence in the Town of Southington, Hartford County, Connecticut. As part of the study, ATSDR was given the task of determining population exposure to contaminated groundwater that was distributed in the town's water distribution system. To address the complex engineering issues associated with exposure assessment, ATSDR relied on the resources of the Exposure-Dose Reconstruction Cooperative Agreement Project. The main problem in addressing this issue was the time limitations imposed on ATSDR to find a solution to the problem. A solution to the problem was requested by CDHS within a period of 4 to 6 months. Based on this request ATSDR Exposure-Dose Reconstruction project officer contacted Ga Tech research program during September 1994 an requested us to devote our efforts to solve the problem and provide them with the analysis results within a period of 4 to 6 months. In order to address this urgent problem Ga Tech principal investigator decided to allocate all resources of the project to finding a solution to this problem and providing ATSDR with reliable estimates of exposure using GIS integrated pipe network analysis during the second project period. The project was completed in time and the results were submitted to ATSDR in a final report titled "A Public Health Analysis of Exposure to Contaminated Municipal Water Supplies at Southington, Hartford County, Connecticut."

This research effort, was not included to the initial research program proposed by the principal investigator, and was undertaken as an additional effort at the request of ATSDR project officers. Since the problem posed to ATSDR by the CDHS is an extremely important health assessment problem with nationwide applications and the engineering analysis provided by Ga. Tech is an extremely useful and practical but preliminary solution to the problem at hand. Ga Tech principal investigator recommends that ATSDR may like to pursue this research in the future to develop a user friendly application tool for the analysis of similar problems. This unplanned research effort requested by ATSDR delayed the ongoing efforts at Ga Tech by three quarters during the second year of the research program which influenced the progress of the third project period. That is why the development of surface water pathway tools were moved to the fourth project period and joined with the animals and plants pathway. Due to this delay, an extension of the four year project period to five years may be requested by Ga. Tech at the completion of the first four years in order to complete the tasks of the program proposed.

- **Development of user friendly GIS interface programs**:

It is our understanding that ATSDR's needs for computational tools in the area of health assessment is multilevel. The range of complexity of these tools may vary between screening tools, similar to the analytical computational environment described above, to the sophisticated GIS integrated multimedia modeling tools which may be used to analyze more complex cases. Given the number of sites that needs to be analyzed by ATSDR periodically and given the variability in complexity of the contaminant migration pathways in these sites, there would be a need for sophisticated approaches as well as the screening tools. Thus, in addition to the analytical tool development phase of the project, we have developed and submitted user friendly GIS interface programs to simplify the analysis steps necessary in these complex cases. Our initial efforts in category was concentrated towards the development of a shell structure for the GISPlus software which is presently used by ATSDR. This shell program simplifies the manipulation of data structures within a GIS integrated computation and the interaction of the complex simulation tools with the GIS system. The preliminary shell structure submitted to ATSDR during the first period of the project may describe our line of thought in this effort. In its present form this software is being tested and used to evaluate site specific conditions for the ground-water pathway at ATSDR and Ga. Tech. In this effort, in addition to the general shell structure submitted to ATSDR, certain coordinate transformation routines and data base generation routines, compatible with the existing ground-water flow and contaminant transport models, has been developed and submitted to ATSDR for beta testing. These codes were tested and used successfully in site specific applications by ATSDR professionals. This aspect of the research program is still under development and revisions to the code will be supplied to ATSDR for their beta testing.

- **Adaptation of existing ground-water flow models to GISPlus software**:

  The PC-based GIS system in use at ATSDR is the GISPlus system. The implementation of existing ground-water pathway analysis tools required substantial revision of these codes to make them compatible with the GISPlus system. Although this is an ongoing task, our initial efforts provided ATSDR with these tools which are now in use in predicting ground-water flow patterns in several sites of interest to ATSDR. We are in the process of adding contaminant transport models to this system in the area of subsurface analysis. These codes were tested and used in site specific applications by ATSDR professionals during the second and third period of the research program and the results are shared with several federal and state agencies involved in the program.

2. PRODUCTS SUBMITTED TO ATSDR, USDHHS

During the third year of the cooperative agreement the following computational software were submitted to ATSDR for their evaluation and beta testing. Some of this software are still in the development stage and should not be considered to be a final product. All of these products are presently used by ATSDR health assessors in evaluating health consequences of contaminants released to subsurface pathways.

(i) **A**nalytical **C**ontaminant **T**ransport analysis **S**ystem (ACTS Version 2.70)

(ii) Numerical Groundwater flow and **C**ontaminant **T**ransport Analysis **Tools** (SLAM_GIS and CLAM_GIS)

(iii) ARCVIEW interphase for Numerical Groundwater flow and Contaminant Transport Analysis Tools(SLAM_GIS and CLAM_GIS) (The beta test version of this software will be submitted to ATSDR during the end of project period three, summer of 1996)

3. RESEARCH ACTIVITIES FOR PROJECT YEAR 4

As the third year effort, the progress made in all of the activities summarized above are substantial. This progress was in addition to an unplanned GIS based Pipe Network Analysis research activity requested by ATSDR. The research effort on this activity was partially extended to the third project year. Ga Tech project director welcomes such requests since in our cooperative agreement the basic goal is to satisfy the technical needs of ATSDR as they arise and provide ATSDR with expertise utilizing resources of Ga. Tech. This effort was an excellent example of this cooperation. Technical papers published, which were the outcome of this effort, not only was accepted for publication in prestigious journals and conferences such as Archives of Environmental Health and HydroGIS'96 an International Conference, but also these technical publications received the prestigious USDHHS Engineering Literary Technical Excellence Award.

Our ongoing efforts will be directed towards the completion of the tasks and improving the tools we are developing for ATSDR during the fourth year of the project. In this effort, additional pathways described above will be incorporated into the computational environment. These tools will be periodically submitted to ATSDR for their evaluation and beta testing.

The primary pathway that will be analyzed during the fourth project period is selected to be the surface water and animals and plants pathway. Analytical tools that will be developed to evaluate exposure in these pathways will include, near field far field surface water diffusion dispersion models and other empirical models which may be used for animal and plant pathway exposure analysis. Monte Carlo simulations will also be incorporated into this analysis. Details of this computational processes were described in the original proposal submitted to ATSDR which will not be repeated here.

In addition to the inclusion of this pathway models to the ACTS software, the GIS integrated groundwater and contaminant transport and fate models developed for the GISPlus software will be extended to PC ArcInfo based platform since this is now the preferred platform for ATSDR. In this effort we intend to extend the user friendly interface developed for GISPlus platform to ArcInfo platform. This task will cover a major portion of the fourth year effort of the present project.

For technology transfer efforts workshops are planned for the fourth project period. During these workshops the use of the software submitted to ATSDR will be reviewed and the technical background will be explained.

4. TECHNICAL PUBLICATIONS

Based on the progress made during the second year of the research program, several technical publications and reports were published or submitted for publication. These research reports or technical papers are the outcome of the research effort of the third project year. The following technical publications were accepted for publication in refereed journals or were accepted for inclusion in the proceedings of the conferences listed below.

1. Maslia, M. L., M. M. Aral, and T. M. Radtke, "Conducting Exposure Assessment of Populations by Integrating Environmental Transport Models, Demographic Analysis and Geographic Information Systems", Assessing and Managing Health Risks from Drinking Water Contamination: Approaches and Applications, IAHS Publ. No. 233, pp. 221-233, September, 1995.

2. Maslia, M. L., and M. M. Aral, "Evaluation of Human Exposure to Contaminated Water Supplies using GIS and Modeling", HydroGIS'96 Application of Geographic Information Systems in Hydrology and Water Resources Management, IAHS Publ. No. 235, pp. 243-252, April, 1996.

3. Maslia, M. L., and M. M. Aral, "A Public Health Analysis of Exposure to Contaminated Municipal Water Supplies at Southington, Hartford County, Connecticut," ATSDR Health Assessment Study, Submitted as a part of Exposure-Dose Reconstruction Research Program, August 20, 1996.

4. Aral, M. M., M. L. Maslia, G. Ulirsch, and J. J. Reyes, "Estimating Exposure to VOCs from Municipal Water Supply Systems: Use and Application of a Computational Model," *Archives of Environmental Health*, (in publication), August, 1996.

5. PROPOSED BUDGET AND JUSTIFICATION

With this proposal continuation of the cooperative agreement between ATSDR USDHHS and Georgia Institute of Technology is proposed. The fourth year budget for the services of the personnel and other resources are itemized below. The budget proposed for the fourth project year is not significantly different than the one proposed for the third year. Main differences reflect the changes in faculty salaries as anticipated.

Budget summary for third year :

	ATSDR Funds Allocated to the Project	Matching Funds Source GA.TECH
a. Salaries and Wages :		
Principal Investigator	$ 36,000.00	$ 16,500.00
Research Faculty	$ 15,000.00	--
7 full time Ph.D. students	$ 115,500.00	--
One full time M.S. students	$ 8,000.00	--
Secretarial Support	$ 2,000.00	--
Total (excluding students)	$ 53,000.00	$ 16,500.00
Total (including students)	$ 176,500.00	
b. Fringe Benefits : (excluding students)		
24.8 % of salaries	$ 13,144.00	$ 4,092.00
c. Supplies :	$ 6,000.00	--
d. Publication costs :	$ 3,000.00	--
e. Travel :	$ 5,000.00	--
f. Equipment (comp./hardware):	$ 18,000.00	--
g. Total direct costs :	$ 221,644.00	$ 20,592.00
h. Indirect costs :		
43 % of Direct Costs (excluding equipment)	$ 87,567.00	$ 8,855.00
I. Total amount proposed :	$ 309,211.00	$ 29,447.00
j. GA.TECH share for the 4th year :	--	$ 29,447.00
k. ATSDR share for the 4th year:	$ 309,211.00	--
l. ATSDR share for the 4th year excluding the unobligated funds:	$ 294,602.00	

Justification of Budget :

The proposed budged will be primarily used to underwrite graduate and post-graduate student research funds, and secondarily to support release time for the research faculty. This approach will foster the training of professionals specialized in this much needed area of research and increase the awareness of engineering and science students on health related issues. This trained resource pool will be of vital importance to ATSDR's and also to other federal and state health organization's needs in the future. Part of the research funds requested will be used to purchase certain computer equipment and/or software. The main purpose of this purchase is to develop the proposed simulation tools on computational platforms which are similar to the computational and data processing environment available at ATSDR and utilize the most recent and advanced software available in the literature. The compatibility between the computational systems at ATSDR and Ga. Tech is essential and will definitely simplify the technology transfer phase of the proposed study. These dedicated computational equipment will only be used by the graduate students and research scientists for the exclusive purposes of the proposed study.

Budget Breakdown:

Personnel	Annual Salary	Percentage of effort	No. of Months	Amount Requested(Federal Funds)
Principal Inv.	$ 83,000	43 %	5	$ 36,000.00
Research Fac.	$ 75,000	20 %	2	$ 15,000.00
1 PhD Student	$ 16,500	33 %	12	
Total PhD Students (7)				$ 115,500.00
1 MS Student	$ 8,000	33 %	9	
Total MS Students (1)				$ 8,000.00
Secretary	$ 25,000	8 %	1.5	$ 2,000.00

Principal Investigator :	Dr. M. M. Aral is the principal investigator of the Exposure Dose Reconstruction Research program. He is the main contributor and the coordinator for all research activities in the proposed program. His contribution and time will form the nucleus of all research activities proposed in this program.
Research Faculty:	On an as needed basis services of several other faculty members will be requested under this category.
PhD Students (7 students)	Contribution of several PhD students are an essential element of this research program. At the present there are seven PhD students working in the program. Continuous support for these Ph.D. students is essential for the research program.

MS Students (1 students)	Contribution of MS students are an essential element of this research program. At the present there is one MS student working in the program. We anticipate that this number will not change in the fourth project year.

Fringe Benefits:

Fringe benefits are applicable to direct salaries and wages of all personnel excluding students. The present fringe benefit rate is 24.8 %. This rate may change during the academic year 1996-97. However, this change will not effect the total amount requested from federal funds for the fourth year of the cooperative agreement.

Travel:

	Travel	Lodging and Meals	Registration
Conference 1 (Europe)	$ 1,200.00	$ 400.00	$ 200.00
Conference 2 (Middle East)	$ 1,200.00	$ 600.00	$ 600.00
Conference 3 (USA)	$ 500.00	$ 100.00	$ 200.00

Total Travel Budget : $ 5,000.00

It is expected that the principal investigator will participate in at least three conferences during the academic year 1996-97 related to the research program topic. The funds in this category will be only used by the principal investigator for this purpose. The total cost of this category will be within the range allocated for the program.

Equipment:

Unit #	Quantity	Unit Cost	Total Cost
Dell Pentium PC.	2	9,000.00	18,000.00

We anticipate that we will be adding to the initial equipment purchased throughout the duration of the project as future needs arise. The equipment purchased for the Exposure Dose Reconstruction Research program is compatible with the present standards and other computational equipment which is used by ATSDR and will remain the property of ATSDR. We anticipate to purchase two computers for the research program. The total cost of this equipment will be within the range allocated for the program.

Supplies:

The computational tools developed for the program requires special software as utility tools. We anticipate to purchase these tools and use them in or research efforts. These software tools include items such as Windows95 graphics software, and updates on Visual Basic Professional Tool, Visual C++, Communication Tools, Power Fortran, their updates and other new products that we will incorporate in our software. The total cost of this supplies purchase will be within the limits allocated for the program ($ 6,000.00).

Publication Costs:

It is anticipated that the publication cost for the reports and users manuals for the software prepared for ATSDR will be around $ 3,000.

Contractual: None

Consultant: None

Other: None

Indirect Costs:

Overhead rates are applicable to direct salaries and wages of all personnel and other expenses excluding equipment purchases. The present overhead rate is 43 %. This rate may change during the academic year 1996-97. However, this change will not effect the total amount requested from federal funds for the third year of the cooperative agreement.

Unobligated Funds:

As reported to CDC contracts administration office, we have unobligated funds (in the amount of $14,609.00) remaining from the second project year. The first reason for this unobligated funds amount was due to shifting the principal investigator's conference trip charges expected to occur during the second year budget period, to the third year budget period. This shifting was necessary because of a change in the dates of the conference. Thus, the expenses of the conference trip was charged to the third budget year. The second reason was that the principal investigator decided to hold on to some equipment and software purchases, in order to purchase the more recent (upgraded) versions of the software and the equipment. We intend to include and use this amount in the fourth project year. The budget presented above includes this amount.

BIOGRAPHICAL SKETCH

Dr. Mustafa M. Aral

Personal Data Summary

Born	: February 26, 1945, Ankara, Turkey
Citizenship	: U.S.A.
Home Address	: 2974 Cravey Dr. NE., Atlanta, GA. 30345

Business Address

School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
Buss. Phone: (404) 894-2243 Fax Phone: (404) 894-5111

Professional Registration

Professional Engineer : GA : 15254
Professional Ground Water Hydrologist, National Registration : No.: 649

Educational Background

School of Civil Engineering, Georgia Institute of Technology, Ph.D. in Water Resources Engineering with minor in Numerical Analysis and Applied Mathematics, September 1971.

School of Civil Engineering, Georgia Institute of Technology, M.S. in Civil Engineering with major in Environmental and Water Resources Engineering, June 1969.

Department of Civil Engineering, Middle East Technical University (Ankara, Turkey), B.S. in Civil Engineering, June 1967.

Professional Experience

1995-Present	Professor	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1983-1995	Associate Professor	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1978-1983	Visiting Professor	School of Civil and Environmental Engineering, Georgia Institute of Technology.
1974-1983	Adjunct Professor	At Marine Sciences Department, Civil Engineering Department, Engineering Science Department, Middle East Technical University.

1977-1983	Associate Professor	Mathematics Department, Middle East Technical University.
1975-1978	Assistant Chairman	Mathematics Department, Middle East Technical University.
1971-1977	Assistant Professor	Mathematics Department, Middle East Technical University.

Publications

42. **Aral, M. M.**, Ground Water Modeling in Multilayer Aquifers - Steady Flow, *Lewis Publishers Inc.*, February, 1990 (Book).
43. **Aral, M. M.**, Ground Water Modeling in Multilayer Aquifers - Unsteady Flow, *Lewis Publishers Inc.*, March, 1990 (Book).
44. Tang, Y., and **Aral, M. M.**, Contaminant Transport in Layered Porous Media: A. General Solution, *Water Resources Research*, Vol. 28, No. 5, pp. 1389-1397, 1992.
45. Tang, Y., and **Aral, M. M.**, Contaminant Transport in Layered Porous Media: B. Applications, *Water Resources Research*, Vol. 28, No. 5, pp. 1399-1406, 1992.
46. Ratzlaff, S., **Aral, M. M.**, and Alkhayyal, F., Optimal Capture Zone Design Using Segmental Velocity Direction Constraints, *Groundwater Journal*, Vol. 30, No. 4, pp. 607-612, 1992.
47. **Aral, M. M.**, and Tang, Y. Flow Against Dispersion in Two Dimensional Aquifers, *Journal of Hydrology*, Vol. 140, pp. 261-277, 1992.
48. Maslia, M., **Aral, M. M.**, and Houlihan, M., "Evaluation of Ground-Water Flow Regime at a Landfill with Liner System," *Journal of Environmental Science and Health*, Vol. A27, No. 7, pp. 1793-1816, 1992.
49. Maslia, M., **Aral, M. M.**, and Gill, H. E., "The Importance of Hydrogeologic Controls on Remedial Action Alternatives," *Geophysical Society of America*, Southeastern Section Meeting, Contaminant Hydrogeology Session, Vol. 24, No. 2, pp. 53, 1992.
50. Maslia, M., **Aral, M. M.**, Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Determine Health Implications of Human Exposure Resulting from Remediation Activities at Hazardous Waste Sites," Report for: *Division of Health Assessment and Consultation, DHHS-ATSDR*, 20p, November 5, 1992.
51. **Aral, M. M.**, Maslia, M. and Williams, R., "Integration of GIS and Environmental Transport Models for Exposure Assessment of Populations," Water Resources Bulletin, (submitted for publication), 1993.
52. Maslia, M., **Aral, M. M.**, Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Determine Human Exposure Resulting from Remediation Activities at Hazardous Waste Sites," Proceedings of the Water Environment Federation Specialty Conference *How Clean is Clean*, 85p, January 10-13, 1993.
53. Maslia, M., **Aral, M. M.**, Williams, R., Williams, S., Hayes, L. and Wilder, L., "Use of Computational Models to Reconstruct and Predict Trichloroethylene Exposure," Proceedings of the International Congress on the Health Effects of Hazardous Waste, 22p, 1993.
54. **Aral, M. M.**, Maslia, M., and Williams, R., "Ground-Water Remediation Using Smart Pump-and Treat," *Ground Water Journal*, Discussion, Vol. 31, No. 4, pp. 680-681, 1993.

55. **Aral, M. M.**, C. Shea and Al-Khayyal, F., "Optimization Methods in Ground Water Management," Review Chapter in Volume 9, "Applications of Management Science: Network Optimization Applications," JAI Press Inc., 1993 (in publication).
56. Maslia, M. L. and **Aral, M. M.**, "Health Implications Associated with Hazardous Waste Site Clean-Up Goals: A Case Study of Trichloroethylene (TCE) Contamination", Proceedings of the Annual Meeting of the Geological Society of America, Boston, 1993.
57. Maslia, M. L. and **Aral, M. M.**, "Conducting Exposure Assessment of Populations by Integrating Environmental Transport Models, Demographic Analysis, and Geographic Information Systems", Proceedings of the International Symposium on Assessing and Managing Health Risks from Drinking Water Contamination: Approaches and Applications, Rome, Italy, September 1994.
58. Maslia, M. L., M. M. Aral, and T. M. Radtke, "Conducting Exposure Assessment of Populations by Integrating Environmental Transport Models, Demographic Analysis and Geographic Information Systems", Assessing and Managing Health Risks from Drinking Water Contamination: Approaches and Applications, IAHS Publ. No. 233, pp. 221-233, September, 1995.
59. Maslia, M. L., and M. M. Aral, "Evaluation of Human Exposure to Contaminated Water Supplies using GIS and Modeling", HydroGIS'96 Application of Geographic Information Systems in Hydrology and Water Resources Management, IAHS Publ. No. 235, pp. 243-252, April, 1996.
60. Maslia, M. L., and M. M. Aral, "A Public Health Analysis of Exposure to Contaminated Municipal Water Supplies at Southington, Hartford County, Connecticut," ATSDR Health Ass Study, Submitted as a part of Exposure-Dose Reconstruction Research Program, p 56, August 20, 1996.
61. Aral, M. M., M. L. Maslia, G. Ulirsch, and J. J. Reyes, "Estimating Exposure to VOCs from Municipal Water Supply Systems: Use and Application of a Computational Model," *Archives of Environmental Health*, (in publication), August, 1996.

Expertise Areas

Research, teaching and engineering experience in the following specific areas :

- Fluid mechanics, Hydraulics Engineering
- Environmental simulations and fate
- Analytical and numerical studies in surface water, ground-water and air pollution
- Evaluation of ground water and surface water monitoring data
- Ground water flow and contaminant transport modeling in aquifers
- Ground water resources evaluation and management
- Disposal and ground water quality effects of hazardous substances, aquifer remediation
- Saturated and unsaturated ground water flow analysis
- Miscible and immiscible ground water flow analysis
- GIS applications in environmental systems

OMB Approval No. 0937-0189
Expiration Date: March 31, 1995

CHECKLIST

Public Burden Statement: Public reporting burden for this collection of information is estimated to average 10 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate, or any other aspect of this collection of information, including suggestions for reducing this burden, to PHS Reports Clearance Officer, ATTN: PRA, Hubert H. Humphrey Bldg., Room 721-B, 200 Independence Ave., S.W., Washington, D.C. 20201, and to the Office of Management and Budget, Paperwork Reduction Project (0937-0189), Washington, D.C. 20503.

NOTE TO APPLICANT: This form must be completed and submitted with the original of your application. Be sure to complete both sides of this form. Check the appropriate boxes and provide the information requested. This form should be attached as the last page of the signed original of the application. This page is reserved for PHS staff use only.

Type of Application: ☐ NEW ☒ Noncompeting Continuation ☐ Competing Continuation ☐ Supplemental

PART A: The following checklist is provided to assure that proper signatures, assurances, and certifications have been submitted.

	Included	NOT Applicable
1. Proper Signature and Date for Item 18 on SF 424 (FACE PAGE)	☒	
2. Proper Signature and Date on PHS-5161-1 "Certifications" page	☒	
3. Proper Signature and Date on appropriate "Assurances" page, i.e., SF-424B (Non-Construction Programs) or SF-424D (Construction Programs)	☒	

4. If your organization currently has on file with DHHS the following individual assurances, please identify which have been filed by indicating the date of such filing on the line provided. Georgia Tech is audited annually by the Office of
   - ☐ Civil Rights Assurance (45 CFR 80) Federal Compliance Programs.
   - ☐ Assurance Concerning the Handicapped (45 CFR 84) ______
   - ☐ Assurance Concerning Sex Discrimination (45 CFR 86) ______
   - ☐ Assurance Concerning Age Discrimination (45 CFR 90 & 45 CFR 91) ______

	Included	NOT Applicable
5. Human Subjects Certification, when applicable (45 CFR 46)	☐	☒

PART B: This part is provided to assure that pertinent information has been addressed and included in the application.

	YES	NOT Applicable
1. Has a Public Health System Impact Statement for the proposed program/project been completed and distributed as required?	☐	☒
2. Has the appropriate box been checked for item #16 on the SF-424 (FACE PAGE) regarding intergovernmental review under E.O. 12372 ? (45 CFR Part 100)	☒	
3. Has the entire proposed project period been identified in item #13 of the FACE PAGE ?	☒	
4. Have biographical sketch(es) with job description(s) been attached, when required ?	☒	☐
5. Has the "Budget Information" page, SF-424A (Non-Construction Programs) or SF-424C (Construction Programs), been completed and included ?	☒	
6. Has the 12 month detailed budget been provided ?	☒	☐
7. Has the budget for the entire proposed project period with sufficient detail been provided ?	☐	☒
8. For a Supplemental application, does the detailed budget only address the additional funds requested ?	☐	☒
9. For Competing Continuation and Supplemental applications, has a progress report been included ?	☒	☐

PART C: In the spaces provided below, identify the applicant organization's administrative official to be notified if an award is made and the individual responsible for directing the proposed program/project.

Name, title, organization, address and telephone number of the administrative official to be notified if an award is to be made.

Janis L. Goddard, Contracting Officer
Georgia Tech Research Corporation
Georgia Institute of Technology
Atlanta, Georgia 30332-0420
(404) 894-4817

DHHS 12 DIGIT EIN FOR APPLICANT ORGANIZATION (If already assigned)

Name, title, organization, address and telephone number of the program director/project director/principal investigator designated to direct the proposed project or program.

Dr. M. M. Aral, Associate Professor
School of Civil & Environmental Engr.
Georgia Institute of Technology
Atlanta, GA 30332 (404) 894-2243

SOCIAL SECURITY NUMBER

HIGHEST DEGREE EARNED: Ph.D.

(OVER)

PART D: A private, nonprofit organization must include evidence of its nonprofit status with the application. Any of the following is acceptable evidence. Check the appropriate box or complete the "Previously Filed" section, whichever is applicable.

☐ (a) A reference to the organization's listing in the Internal Revenue Service's (IRS) most recent list of tax-exempt organizations described in section 501(c)(3) of the IRS Code.
☐ (b) A copy of a currently valid Internal Revenue Service Tax exemption certificate.
☐ (c) A statement from a State taxing body, State Attorney General, or other appropriate State official certifying that the applicant organization has a nonprofit status and that none of the net earnings accrue to any private shareholders or individuals.
☐ (d) A certified copy of the organization's certificate of incorporation or similar document if it clearly establishes the nonprofit status of the organization.
☐ (e) Any of the above proof for a State or national parent organization, and a statement signed by the parent organization that the applicant organization is a local nonprofit affiliate.

If an applicant has evidence of current nonprofit status on file with an agency of PHS, it will not be necessary to file similar papers again, but the place and date of filing must be indicated.

Previously Filed with: *(Agency)* ____________ on *(Date)* ____________

INVENTIONS

If this is an application for continued support, include: (1) the report of inventions conceived or reduced to practice required by the terms and conditions of the grant; or (2) a list of inventions already reported, or (3) a negative certification.

EXECUTIVE ORDER 12372

Effective September 30, 1983, Executive Order 12372 (Intergovernmental Review of Federal Programs) directed OMB to abolish OMB Circular A-95 and establish a new process for consulting with State and local elected officials on proposed Federal financial assistance. The Department of Health and Human Services has implemented the Executive Order through regulations at 45 CFR Part 100 (Intergovernmental Review of Department of Health and Human Services Programs and Activities). The objectives of the Executive Order are to (1) increase State flexibility to design a consultation process and select the programs it wishes to review, (2) increase the ability of State and local elected officials to influence Federal decisions and (3) compel Federal officials to be more responsive to State concerns, or explain the reasons.

The regulations at 45 CFR Part 100 were published in the Federal Register on June 24, 1983, along with a notice identifying the Department's programs that are subject to the provisions of Executive Order 12372. Information regarding PHS programs subject to Executive Order 12372 is also available from the appropriate awarding office.

States participating in this program establish State Single Points of Contact (SPOCs) to coordinate and manage the review and comment on proposed Federal financial assistance. Applicants should contact the Governor's office for information regarding the SPOC, programs selected for review, and the consultation (review) process designed by their State.

Applicants are to certify on the face page of the SF-424 (attached) whether the request is for a program covered under Executive Order 12372 and, where appropriate, whether the State has been given an opportunity to comment.